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ARGENTINE SPACE ASSETS

by

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This thesis is an attempt to define how some of the commercial space assets already in use or under development could be useful to the Argentine Navy as tools for better accomplishment of their basic missions. Research efforts involved investigating part of what is available on the international market and some space related international laws and policies that may represent limits for military use of civilian assets. Basically divided in two main areas , communications and remote sensing, this thesis covers the basics of GEO and LEO communication satellites and provides an overview of what could be expected from commercial remote sensing systems. Through examples, the feasibility of using civilian space assets in the military is demonstrated. Finally, an objective analysis is made to define the best approach to improve Argentine Navy space capabilities.

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ARGENTINE SPACE ASSETS

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requirements for the degree of

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ABSTRACT

This thesis is an attempt to define how some of the commercial space assets already in use or development could be useful for the Argentine Navy as a tool for better accomplishment of their basic missions. Research efforts involved investigating part of what is available on the international market and some international laws or policies referred to space that may represent limits for military use of civilian assets. Basically divided in two main areas , communications and remote sensing, this thesis cover the basics of GEO and LEO communication satellites, and provides an overview of what could be expected from commercial remote sensing systems. Through examples, the feasibility of using civilian space assets in the military is demonstrated. Finally, an objective analysis is made to define the best approach to improve Argentine Navy space capabilities.

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Above all, I want to thanks Marta, my wife and mother of our five children, for being indefatigable and supporting mate, for being kind and unwavering, but mainly for teaching me the secret of not to worry about the things we can not change.

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I. INTRODUCTION

The Argentine Navy can increase its use of satellite services to more efficiently and effectively accomplish its missions. Its current use of space is limited to commercial communications satellites on rare occasions such as remote deployments. Although this sounds strange to many people who live in a country in which high technology, such as satellites, nuclear power, computers, are commonplace, Argentina in general, and the Navy in particular, are years behind the developed countries in space issues. I will not attempt to explain why this is so. The reasons and philosophy for this situation were explained by retired Argentine Navy Captain Nestor Antonio Dominguez in his book *Satelites* (Tomo 2) [Dominguez, 1991].

He was very effective in opening people's minds and worked hard to make politicians and top navy officers understand that space was a very powerful tool that could benefit the whole country. His effort contributed significantly to the establishment of a clear Argentine Space Policy, and at least a few of our achievements in space were because of him.

My goal is to determine how the Argentine Navy can best use space technology, given the current national policies and international constraints, under the most critical budget restrictions, and at a time when apparently every civilian space program is looking for institutional support. Many institutions are beginning to believe that some civilian space programs are good enough for some military applications. Since the end of the Second World War, military forces have first developed technology then later released it

for civilian applications. Recently, the former United States Secretary of Defense, William Perry encouraged his military organizations to use civilian devices and manufactured components to develop new military technology. The programs that did it saved two-thirds of the cost of using components designed specifically for the military [Perry, 1996]. CHALLENGE ATHENA, which used INTELSAT satellites for specific types of communications, was a good example of using civilian space assets for military purposes [Shaw, 1995].

The Argentine Navy should also be able to use civilian space assets to satisfy defense requirements. This is not only true for Argentina but should also be true for most Nations willing to support a peaceful world. I will try to figure out which space assets the Argentine Navy can get and how much it would cost to use them to meet specific Argentine Navy requirements.

Among the possible space asset applications, there are four which, generally speaking, can fulfill the needs of most of the world's navies: navigation, meteorology, communications and remote sensing. Because they are all closely related to human needs, they represent tremendous commercial possibilities in open markets. It is virtually impossible to keep their use exclusively within the military or confined to a limited number of U.S. allies. For example, the Global Positioning System (GPS), which was created for military purposes, is also very useful for commercial navigation, and it represents a significant contribution to the safety of ocean travel. It is not the space asset in itself, but the way in which it is used that makes it useful for military purposes.

Looking at recent global events, which have been characterized by the political and commercial opening of the former Soviet Union nations, we can easily understand why technology that was restricted just a few years ago is now widely available, and all countries are now encouraged to use it. Military as well as civilian space programs are starting to be considered as a potential vehicle for international cooperation in the near future. As Dr. Ken Chow (Deputy Manager for Lockheed Martin Missiles and Space) said in a recent speech, "cost is a driving factor and the defense budget of every western nation will be under pressure." [Chow, 1997]

In reality, no country is free of budget restrictions, and no program can be developed for use by a select few, so the decision to share technology and costs is a desirable one. Probably, only nations who have clearly defined military space intentions can take part in programs like the international MILSATCOM (Such as England, France and Germany), and to have defined intentions requires an understanding at the highest levels of the implications of using space assets.

Why are space assets so valuable to military organizations? Just thinking for a moment about the evolution of the operational manuals in the Argentine Navy, most of them are derived from U.S. publications containing allied doctrine.[1] I can remember how different warfare concepts have developed through the years. Today, the current training of our officers involves sophisticated tactics in Antisubmarine Warfare, Antiair Warfare, Antisurface Warfare, Electronic Warfare, and Amphibious Warfare. In the future, I believe we will need to include Space Warfare aspects in our preparation.

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[1] Refer to publications such as Allied Tactical Procedures (ATP -1 Vol 1 and ATP -1 Vol 2) and Naval Warfare Procedures series.

The U.S. Navy created The Naval Space Command in 1983, which provides efficient support to the naval warfighter throughout the world. Space assets have been a part of all U.S. military activities since the time of Corona, the first spy satellite developed by U.S. [Brown, 1996]. However, space is absolutely critical to the U.S. military today. The Persian Gulf War showed us that space capabilities are driving the new conceptions about war. Just as airspace control has always been one of the most important factors in a battle, space control is now critical to any operation that involves U.S. forces. As in other theaters of conflict, the combatant able to deny the use of the military benefits that space assets provide to his adversary can have a distinct advantage [Lee, 1994].

The most critical tactical aspects of a battle can be greatly improved by using the appropriate space system. Reliable, jam-resistant communications with a wider spectrum of frequencies and data transmission capability can be the best way to transmit the information obtained from remote sensors to the right person quickly enough to support decision making. Imagery from remote sensors can be complemented by appropriate meteorological information from satellites and referenced to an accurate location from the space-based Global Positioning System. The end result of this process might be a few commands sent to the guidance system of the next waiting missile. In other words, space capabilities provide *information dominance* to the user who has it, relative to the user who does not.

I will not promote the idea that Argentine needs something similar to the U.S. space structure; the comparison could never be reasonable. Space is valuable to the United States military because of its mission, objectives, operational theaters and the size

of its forces. Also, what is good for the U.S. might not be cost-effect for Argentine. Nevertheless, we can learn from the U.S. example. It is understandable that the U.S. military requires significant space capabilities as well as control over those services, so it spends more than ten billion dollars a year just on space. Small countries cannot invest this kind of money in such systems, so the best approach may be to learn how to use what already exists, if it is available.

Argentina is now conducting small experiments in space. One example is the Satelite de Aplicaciones Cientificas (SAC -B) dedicated to studying space phenomena, including solar flares, gamma ray bursts, diffuse cosmic X-ray and energetic neutral atoms [Space News, 1996]. Argentina is also using some civilian space assets to support general meteorology and civil and military navigation. It is using civilian satellite communications on a commercial basis, and some provinces are starting to buy remotely sensed imagery to support regional development [Paige, 1996].

Finally, it may be difficult to share some spaceborne remote sensing or military communications systems, but, in today's world, when the most nations are willing to live in peace, arms races and space races are just not feasible.

II. MISSIONS AND REQUIREMENTS

A. BACKGROUND

The Argentine Navy is one of the three forces established in accordance with the Argentine Constitution [Constitucion, 1994]. Its main objective is to contribute to the national defense in order to protect and warrant the national interests by means of appropriate sea control. To accomplish this mission, the Argentine Navy operates surface ships, airplanes, terrestrial units (Marine Corps) and submarines (Appendix A). The vastness of the Argentine maritime littoral extension and the claim of sovereignty to the Exclusive Economic Zone (EEZ)[1] is a driving factor in developing requirements for space capabilities.

Since 1989, Argentine foreign policies have been clearly formulated to be consistent with those of the western allied countries. Our participation in the Gulf War and our continued contribution to the United Nations Peacekeeping Forces and Humanitarian Aid Forces (Kuwait, Croacia, Chipre, Haiti, Angola, Somalia) introduced a new mission that demanded structural changes and required a new operational concept. The Navy must now be ready to cooperate with international forces in the most distant theaters. The Air Force and Army are also involved in a general transformation to satisfy new National requirements. Domestically, Argentina has been working hard to resolve remaining border disputes with neighboring countries to reduce the possibility of conflicts,

[1] EEZ is a zone extending two hundred miles from the coastline in which a number of nations, including Argentina, have made claims to exercise sovereign rights over the resources within the zone.

and it is heavily negotiating with United Kingdom to finally resolve the Malvinas dispute.[2] The Armed Forces also has a responsibility to society to perform essential community services. Surplus military capabilities and technologies can sometimes be used to satisfy civilian needs. The Naval Transportation Service, for example, provides transportation to remote, isolated regions in the southern part of the country. Mapping activity is a government responsibility and is better achieved by the Army on land regions, by the Navy for nautical charts, and by the Air Force for aeronautical charts. Therefore, the basic missions of Argentine Navy can be summarized as:

-National Defense

-Maritime Traffic Control

-Peace Keeping Operations

-Humanitarian Aid Operations

-Search and Rescue

-Civic Action[3]

-Ecosystem Protection

-Disaster Prevention

-Disaster Control

-Mapping and charting

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[2] Recommended books related to Malvinas issue:

Signals of War: the Falklands Conflict of 1982 by Lawrence Freedman and Virginia Gamba-Stonehouse [1991].

The Sovereignty Dispute Over the Falkland(Malvinas) Islands by LowellS. Gustafson[1988].

[3] Civic Action means all kind of activities developed by the Navy in order to promote the commonwealth of the citizens under special circunstances. For example, the use of a Patrol boat or a Navy helicopter to evacuate a sick person living in an isolated cattle ranch in Tierra del Fuego.

-Signals and Buoy Maintenance.

-Other missions established by the Government.[4]

These missions have normally been assigned to the Argentine Navy because of the capability of its people, who rely primarily on self-confidence, imagination, creativity, courage and intuition, rather than on technology. The Navy uses relatively old- fashioned methods and procedures, so it encounters the old-fashioned problems, which it is able to solve (for example, exploration, ship identification, and target designation are accomplished without any satellite information).[5] At the other extreme, the American Navy relies on technology and its people are fairly insecure without it. Technology played a key role in the Coalition Forces victory during the Persian Gulf War [Perry, 1991]. During the Malvinas War, the courage and decisiveness of Argentine naval personnel was the dominant factor in the success of some attacks against the British units. However, the War also proved that this courage and decisiveness was not enough to defeat an adversary with overwhelming technological superiority.

The last generation of battleships acquired by the Argentine Navy after the Malvinas War are slowly aging, while computer and data transmission technologies are rapidly advancing. Having civilian technology that is better, faster, cheaper, and more capable of supporting military needs, it seems unfair not to use it.

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[4] This could include anti-narcotic intervention, if it were mandated by the Congress.

[5] During the Malvinas War, most of the Argentine Destroyers were Sumner Class (first commissioned in 1945), and Fletcher Class (first commissioned in 1943) used during the Second War along with weapons and electronic systems of that time. The most recent acquisition of the Argentine Navy is represented by P3 exploration airplanes not longer used by the US.

One of the problems the Argentine navy experienced while participating in Operation Desert Storm was receiving all the information distributed by the Allied Command in a timely manner. The Americans also experienced this problem to some extent, but they are already working on a solution to improve the capability of sending large volumes of information [Shaw, 1995]. The fundamental problem we are facing now is the need for information. We must answer questions about the enemy (and our own forces) quickly and precisely: What are the forces doing? Where are they? When were they there? In what condition are they? The delay or absence of the answers is what we in the military are trying to avoid.

How can space technology help avoid some of the operational problems that the Argentine Navy has experienced in the past? The ongoing technological revolution cannot be ignored. It represents to the military forces a new challenge, and success or failure will depend on rapid adaptation to new scenarios and tools. We can significantly improve de technology-related decision process by understanding that improving military technological capabilities is much more than simply buying the latest model ship, plane or weapon the day before the war starts.

Defining space mission requirements is never an easy task, but with one objective and a few constraints, it will be easier to figure out what system can satisfy those requirements, as opposed to trying to bridge the technology gap from nothing to everything, with unknown budget and constraints. In my analysis, I will focus on two specific missions which I believe have the greatest potential for improvement: communications and remote sensing.

B. GENERAL MISSION STATEMENT

Because the basic missions assigned to the Argentine Navy require coverage of large areas in regional theaters, force projection beyond our borders, and rapid response in critical situations, the Argentine Navy needs to improve its Command, Communications, Control and Information system (C^3I) capabilities, in order to contribute to national and international interests. Space technology can help with this.

This mission statement is too diverse to find a single product that can satisfy the needs of all its elements. First, the expression "C^3I capabilities" requires more detail. In March of 1995, Paul G. Kaminski, discussed the U.S. C^3I system during a briefing to the Research and Development Congressional Subcommittee entitled, "Investing in Tomorrow's Technology Today":

> *Command, control, communications and systems are vital elements in successfully conducting the potential missions and operations of a post -Cold War future. Advances in technology and changes in military doctrine require that our C^3I systems undergo continual modernization. Accordingly, modernization remains a priority for our C^3I programs even under the fiscal constraints facing the Department. To this end we are continuing to move ahead with the modernization efforts needed to ensure that our C^3I systems provide the secure information capabilities needed by war fighters and other command authorities to effectively and successfully prosecute missions anywhere in the world.*

Kaminsky noted other examples. He said that " Battlefield Combat Identification" helps to avoid fratricide casualties and that "Army digitization of the battlefield" helps to get more concentration of power in specific areas. This last concept should be associated with the ability of weapons to respond to digitized information so that by using the

battlefield digitization, it will be possible to send digitized data to direct weapons to the target. [Kaminski, 1995]

William J. Perry, when teaching at Stanford University in 1991, analyzed first the concepts that Kaminski was reinforcing:[6]

> *Command, Control, Communications and Intelligence gives any field commander what the military calls "situation awareness." In Desert Storm, coalition battlefield commanders gained a remarkable awareness of the situation on the battlefield...*

Basically, this awareness meant that they new where the enemy, the friendly forces and their own forces were located and what they were doing. [Perry, 1991]

The U.S. Navy is already developing a doctrine for C^4I (Command, Control, Communications, Computers and Intelligence), so other navies should at least consider ways to approximate it. Naval C^4I includes information systems, and equipment, software, and an infrastructure that enables command authorities to make better decisions.
The four basic functions of C^4I are, *collecting, processing, disseminating, and protecting* the information. Space systems are an important part of C^4I, because they play a key role in linking widely dispersed, forward deployed naval forces with each other. Specific C^4I activities include: collecting the information with remote sensors; processing the information by software able to geolocate, enhance, enlarge, correct and present the information in an understandable format; and disseminating and protecting the information using the most convenient communication channels (ones which have less probability of

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[6] From 1993 to 1997 William J. Perry was US Secretary of Defense. Paul G. Kaminsky was Undersecretary of Defense .

been intercepted by the enemy). Table 2.1 lists a number of C^4I characteristics that define how well the system works. [NDP 6, 1995]

Table 2.1. Common Characteristics or Parameters of Naval C^4I Systems. [NDP 6, 1995]

The C^4I system should be:
Reliable. C^4I systems should be available when needed and perform as intended with low failure rates and few errors. Reliability is also attained by standardizing equipment and procedures; building necessary redundancy ; establishing effective logistics support; and protecting against computer viruses, electronic jamming, and deception. Systems should perform reliably aboard ships and aircraft, in garrison, and in austere field environments.
Secure. C^4I systems should provide commensurate with the user's requirements and the vulnerability of the transmission media to interception and exploitation. Security is achieved by employing appropriate multilevel security protection and cryptographic systems, using transmission security techniques, and educating and training personnel in security procedures.
Timely. intelligence C^4I systems should process and transfer information between decision makers rapidly enough to maintain a high tempo of operations and ensure that our decision and execution cycle remains ahead of any potential adversary's.
Flexible. C^4I systems should be capable of being reconfigured quickly to respond to a rapidly changing environment. Flexibility can be obtained through system design using commercial facilities, mobile or transportable C^4I, or prepositioned facilities.
Interoperable. C^4I systems should ensure that information can be exchanged among all the commanders and forces involved in an operation. Naval C^4I systems also should possess the interoperability required to ensure information exchange in joint and multinational operations and in operations with other government agencies.
Survivable. C^4I systems survivability can be attained by dispersal and protection of key nodes, physical and electromagnetic hardening, and redundancy of communications paths and information processing nodes.

These characteristics, or parameters, will be the driving factors in future analyses of military communication and remote sensing system capabilities. Assuming that the Argentine Navy currently uses space assets for navigation and meteorology to the

maximum extent desirable, it is possible to break my General Mission Statement into two important elements:

1. Mission Statement #1

The Argentine Navy needs a satellite communication systems to better accomplish its basic missions, because the evolution of military actions has shown that Argentina is now engaged in more global missions that require global communications and systems that are compatible with U.S. and allied countries. Satellites are more consistent with the characteristics of C^4I mentioned above (Table 2.1.).

2. Mission Statement #2

The Argentine Navy needs access to remotely sensed data, along with the human and technical tools to process it into information that will help the Navy accomplish its basic missions, because the evolution of military actions has shown that satellite remote sensing provides useful information to support C^4I functions.

C. CONSTRAINTS

Argentina currently has no money allocated for military space development, so any funding would have to come from budgets of existing programs. Allocations for space assets would have to be incorporated into other programs, such as communications or oceanography, or by direct commitment of funds from the Government's budget, which would involve building support through convincing arguments. Any proposed project would have to satisfy the following requirements to have at least a small probability of being funded:

-Be initially inexpensive, in order to minimize initial opposition.

-Be applicable to a short term solution of an existing problem, in order to make it more attractive.

-Have a high benefit to cost ratio.

-Contribute to Argentine foreign policies, because it is in this area that politicians are more interested in military services.

1. Constraint # 1: Limited Funding

Argentine space research started in 1958 under close U.S. tutelage. Argentina launched its first sounding rocket in 1961. Throughout the 1960's, the Argentine Space Program was considered the most advanced in the Third World. In late 1970, an Argentine Castor rocket lifted a 50 kg instrument package to an altitude of 500 Km. Within two years, however, the entire program came to halt, largely to liberate money and skilled personnel for other endeavors, including tactical missile programs and the blossoming nuclear power program. [Papp and McIntyre 1987]

Obviously, the lack of political continuity and the absence of a clear understanding of the significance of space, along with regional problems like subversion and terrorism, contributed to delays and disruptions in the Argentine space programs for years. In 1990, an Academic Commission, created to promote space issues, acknowledged the significance of space in modern life, briefed to the Congress Commission first and then to the Argentine President, Dr. Carlos Saul Menem, about the importance of space. As a result, the C.N.I.E.[7] National Commission of Space Investigation (created by Decreto[8]

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[7] C.N.I.E. Comision Nacional de Investigation Espacial (Spanish).

PEN Nro1873, Jun 18, 1962) was replaced by C.O.N.A.E.[9] National Commission of Space Activities (created by Decreto PEN Nro 995/91) which answers directly to the President.

The next significant decision affecting the future of Argentine space was to award Argentine's orbital position in geosyncrhonous orbit to the international consortium NAHUELSAT, for 24 years starting in 1997. Argentina made its first reservation of a position in geosyncronus orbit in February 1985, and the International Telecommunications Union (ITU) gave its authorization to use it in June of the same year. The rules established by ITU specified that the satellite must be in place within six years. But by 1990, seven different projects were undertaken with no results. The ITU issued two extensions, the last of which expired in June 1994. The Argentine Government had no money for such a demanding development program, so it had two options: give up the orbital space or allow commercial companies to undertake the project and presumably keep some benefits reserved for the Government. The last option was adopted and that is how NAHUELSAT came through. [Dominguez, 1991]

Regarding the decision to develop NAHUEL satellites, Mr. Everett J. Santos, director of the Corporation Financier International, said, "The NAHUELSAT project shows the government strategy of using privatization like an instrument to modernize telecommunications in Argentina... [and] ... benefit the regional economy" [Perea, 1994].

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[8] Decreto PEN: Spanish denomination for decree signed by the president for which Congress approval is not necessary.

[9] C.O.N.A.E. Comision Nacional de Actividades Espaciales (Spanish).

Argentina launched its first communications satellite, *Nahuel 1* to geosynchronous orbit aboard Ariane 4 on January 30, 1997. The second, *Nahuel 2*, is scheduled for launch at the beginning of 1998. The satellite will operate in the Ku band,[10] mainly relaying TV signals with 180 channels. It can simultaneously relay up to 18,000 phone calls and data transmission.

The Nahuelsat consortium (telecommunication company) is composed of Daimler-Benz Aerospace, which has an 11% investment; Aerospatiale (France), 10%; Alenia Spazio (Italy), 10%; A.N.T.E.L.(Uruguay), 6.5%; Banco de la Provincia Group(Argentina), 11.5%; BISA (Argentina), 11.5%; International Finance Corporation 5%; Lampebank International (Luxembourg), 11.5%; Publicom S.A. (Argentina), 5.75%; and Richefore Satellite Holding Co. (Jersey, Chanell Island), 17.5% [Daimler-Benz Aerospace, 1996].

The composition of the consortium and the particular characteristics of the satellite (the number of TV channels and phone signals) clearly show that commercial interests were sufficient to move the participants. However, the success of this government decision will be measured through the quality of new services provided to the population [Clarin 02-01-97].

Another important point is that just as neither national desire, community need, nor technological or scientific interest has justified the big commitment of funds necessary to achieve an entirely Argentine Communications Satellite, there is no need to ask for an exclusively military satellite program, especially at the present time. Hence the first goal,

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[10] Ku is a microwave band just above 10 Ghz. The range of interest for fixed satellite services is between 11 to 14.5 Ghz.

and the best way to acquire some space capability, will be to find the lowest cost option to respond to whatever course of action Argentina takes in the direction of the space.

2. Constraint #2: No action in space matters can be taken that is contrary to the National Policies.

Similar to space decisions in other countries, Argentina is moving forward in space issues because of political support over the past six years. The CONAE developed The National Space Plan (Appendix B), which is a government-approved policy instrument that established the general objectives of space issues to be performed in the short-, medium-, and long- term. The Plan does not address military objectives, probably because the government wanted to keep all of its decisions and strategies in full accordance with international treaties. The inclusion of military objectives could be misinterpreted and might interfere with international cooperation.

The driving factor in present Argentine space activities is the development of capabilities to contribute to scientific programs and commercial activities that might yield economic benefits. Most of the areas of application considered in The Plan can contribute to Navy objectives by providing new capabilities to be used for better and less expensive solutions to the wide range of Navy requirements: [The National Space Plan, 1996]

1) Telecommunications.

2) Use of global positioning systems.

3) Prevention, evaluation and follow-up of natural and anthropogenic disasters.

4) Monitoring and usage of natural resources.

5) Remote detection and control of industrial parameters.

6) Cartography.

7) Supervision and quantification of agricultural and forestry production.

8) Fishing, exploitation and surveillance of coastal and oceanic resources.

9) Studies on environmental quality, degradation and contamination.

10) Local and global meteorological studies.

11) Utilization of soil and underground resources.

12) Design of new methods for development management and administration at a regional scale.

13) Global change.

What makes most of the application areas different from the Navy's needs is the way in which the final product of space systems could be used. The Navy needs space systems to support various military operations. This does not necessarily mean war operations, or aggression. Rather, these needs support peace, hence support global interests. As we demonstrated by our small (but domestically significant) contribution to the coalition forces during the Persian Gulf War, Argentine ships used space assets (primarily Inmarsat) and this use contributed to our mission.

Using space assets, Argentina and other countries can be better prepared to participate in combined exercises, being able to speak the same military language and understand the same basic codes and pieces of information. This would make it easier to build military coalitions when needed.

3. Constraint #3: No action can be taken that is contrary to International Space Law

The International Space Law is a very important group of international agreements that are mostly, but not fully recognized by all nations. They were mainly developed to prevent inappropriate application of international laws in similar ways as they were applied on Earth, so that they did not adversely affect the normal development, investigation and use of space.

As soon as nations and private companies became involved with space, they raised certain legal issues and questions that needed to be answered in order to prevent potential problems. Could nations claim space and divide it into zones, like we do with air space? Could people establish boundaries in space by projecting the boundaries of terrestrial territories into space? Could some nation claim the ownership of the moon or planets? Who would be responsible for the damage caused by an object that reentered the atmosphere after being launched into space? Could some nation put dangerous material like radioactive trash into space?

Nations tried to solve potential problems by making the appropriate treaties and agreements, some of which where just unilateral agreements and others that involved most of the world's nations. The United Nations made many of these agreements immediately after the 1957 launch of Sputnik, the first Soviet Satellite. Between 1967 and 1975, the four most significant agreements were ratified by many countries: [Nathan Goldman, 1987] [OTA-ISS-604, 1994]

The Outer Space Treaty (1967) established the idea that space should be used to benefit all countries and that no one could claim sovereignty on space.

The Rescue and Return of Astronauts and Space Objects(1968) stated that the country in which a spacecraft eventually crashed had to make the maximum possible effort in all rescue activities.

The Convention on Liability (1972) stated that every country has jurisdiction over the objects that they put into space, whether launched by the government or private companies.

The Registration Treaty(1975) stated that all objects sent to the outer space must be registered with the UN.

The most important treaties that military forces must consider are detailed in Table 2.2.

Table 2.2 International Agreements that Limit Military Activities in Space

[Space Handbook, 1993].

Agreement	**Principle/Constraint**
United Nations Charter (1947)	-Made applicable to space by the Outer Space Treaty of 1967 -Prohibits states from threatening to use, or actually using, force against the territorial integrity or political independence of another state (Article 2(4)) -Recognizes a state's inherent right to act individually or collectively, and defend itself when attacked. Customary international law recognizes a

	broader right to self-defense, one that does not require a state to wait until it is actually attacked before responding. This right to act preemptively is known as the right of anticipatory self-defense (Article 51)
Limited Test Ban Treaty (1963)	-Bans nuclear weapons tests in the atmosphere, in outer space, and underwater -States may not conduct nuclear tests or other nuclear explosions (i.e., peaceful nuclear explosions) in outer space or assist or encourage others to conduct such tests or explosions (Article 1)
Outer Space Treaty (1967)	-Outer space, including the moon and other celestial bodies, is free for use by all states (Article I) -Outer space and celestial bodies are not subject to national appropriation by claim of sovereignty, use, occupation, or other means (Article II) -Space activities shall be conducted in accordance with international law, including the UN Charter (Article III) -The moon and other celestial bodies are to be used exclusively for peaceful purposes (Article IV) -Nuclear weapons and other weapons of mass destruction (such as chemical and biological weapons) may not be placed in orbit, installed on celestial bodies, or stationed in space in any other manner (Article IV) -A state may not conduct military maneuvers; establish military bases, fortifications, or installations; or test any type of weapon on celestial Nuclear bodies. Use of military personnel for scientific research or other peaceful purpose is permitted (Article IV)

	-States are responsible for governmental and private space activities and must supervise and regulate private activities (Article IV) -States are intentionally liable for damage to another state (and its citizens) caused by its space objects (including privately owned ones) (Article VII) -States retain jurisdiction and control over space objects while they are in space or on celestial bodies (Article VII) -States must conduct international consultations before proceeding with activities that would cause potentially harmful inference with activities of other parties (Article IX) -States must carry out their use and exploration of space in such a way as to avoid harmful contamination of outer space the Moon, and other celestial bodies, as well as to avoid the introduction of extraterrestrial matter that could adversely affect the environment of the Earth (Article IX) -Stations, installations, equipment, and space vehicles on the Moon and other celestial bodies are open to inspection by other countries on a basis of reciprocity.
Antiballistic Missile (ABM) Treaty (1972)	-Between the U.S. and USSR -Prohibits development, testing, or deployment of space-based ABM systems or components (Article V) -Prohibits deployment of ABM systems or components except as authorized in the treaty (Article I) -Prohibits interference with the national technical means a party uses to verify compliance with the treaty (Article XII)

Liability Convention (1972)	-A launching site is absolutely liable for damage by its space object to people or property on Earth or in the atmosphere (Article II) -Liability for damage caused by a space object, to persons or property on board such a space object, is determined by fault (Article III)
Convention on Registration (1974)	-Requires a party to maintain a registry of objects it launches into Earth orbit or beyond (Article III) -Specific Information about each registered object must be furnished to the UN as soon as practical, including basic orbital parameters and general function of the object (Article IV)
Environmental Modification Convention (1980)	-Prohibits military or other hostile use of environmental modification techniques as a means of destruction, damage, or injury to any other state if such use has widespread, long-lasting, or severe effects (Article 1)

These treaties will probably not be limiting factors for the purposes of my study, because none of the current Argentine Navy's expectations go beyond these stated limits. The only point that we must carefully consider is the right to gather information about other countries by taking pictures from the space. "The prevailing view has been that the governments do not have the right to prohibit the taking of pictures of their countries from orbiting satellites operated by other countries." [Soroos, 1987]

The Declaration of UN Principles in Remote Sensing (1987) was an attempt to definitively solve this issue, but some principles are still vague. Basically, the Declaration established two categories: *sensing states*, which have the capability to do remote

sensing, and *sensed states,* which are the observed states. The Declaration tried to set up the obligation of the sensing states to cooperate with the sensed states by providing the obtained information about the observed state(s) at a reasonable and non-discriminatory cost, as well as the equivalent information about the sensing state, when requested, at reasonable cost. In other words, the law is trying to prevent harmful use of the remote sensing resources. [OTA-ISS-604, 1994]

It is important to remember that the acceptance of satellite reconnaissance as a legitimate "national technical means of verification" by the superpowers was nothing more than a legal way to justify their space activities [Soroos, 1987].

Aside from considerations about the legality of the actions, we can credit remote sensing activities (for example during the Cuban Missile Crisis and The Persian Gulf War) with saving lives and keeping the world powers in equilibrium.

Finally, we need to accept that space assets are part of the systems that military forces can use to protect their countries and maintain the world's balance of power. Space assets can be integrated with weapons, sensors, communication systems, data bases, and computers. The acquisition of space assets should be considered in a similar manner as other military supplies. With the huge expansion that space systems are undergoing, the number of systems offered in the commercial area will notably increase before the year 2000. The prices should correspondingly decrease and make the products more competitive. Today, the worldwide distribution of military duties places many demands for upgrades on those forces that want to be part of the new global community. Such

participation requires the capability to be linked and the capability to be informed, which is also a requirement for self defense and military cooperation with other countries.

III. COMMUNICATION SATELLITES IN GEOSTATIONARY ORBIT

A. INTRODUCTION

Because communication has played one of the most important roles in the history of the humankind, it is only natural that the entire world would exploit any opportunity to get more and better communications. Satellites and computers have contributed to this technological expansion. Satellite communication is one of the most important and profitable commercial applications of space technology. [Wheelon, 1989]

For the past thirty years, Geostationary (GEO) satellites have dominated the communications area. Although the former Soviet Union (F.S.U.) used Low Earth Orbit satellites for communication purposes (Cosmos and Molniya series), the closed policies of this nation did not allow us to know the reasons why, nor did they reveal the advantages or problems the F.S.U. had with this technology.

Since the beginning of the 1990's, the achievement of better technological capabilities and the saturation of the Geostationary orbit, along with the establishment of new needs (more bandwidth, less time delay, lower cost), made the idea of Low Earth Orbit (LEO) constellations attractive. Many LEO communication programs are already

under development,[1] though none of those currently proposed will be able to completely replace the services provided by GEO satellites .

Although conceived to be used commercially, military forces have used civilian GEO communication systems to support their operations. One example was the use of INMARSAT during the Persian Gulf War. Since commercial companies discovered how much business military customers could provide, they have created special packages of services to make their products more attracted to military customers.

B. GEOSTATIONARY SATELLITES

Arthur C. Clarke first proposed the use of space for communications in a 1945 article written for *Wireless World* magazine. Clarke, a physicist and well known science fiction writer, who at that time was secretary of the British Interplanetary Society, postulated that a satellite in an equatorial plane orbit about 36,000 Km from the earth will move around the earth at the same speed that the earth rotates, so it would continuously view to the same spot on the earth. Specifically, a Geostationary Satellite will permanently remain over one point on Earth's equator, and its period of revolution is equal to the Earth's sidereal rotation period of 1436 minutes. The radius of the satellites orbit is 42,164 Km so its altitude above the Earth's surface is 35,786 Km. Clarke also concluded that three satellites separated 120 degrees could view of the entire earth [Hudson, 1990]. Although we can find some problems with these estimations, such as the lack of coverage

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[1] TELEDESIC, GLOBALSTAR, IRIDIUM, ORBCOMM are some of the ongoing LEO programs. I will discuss these in Chapter IV.

at the poles or the North-South and East-West drift of the satellite positions relative to the earth, Clark's basic concept was the driving force behind Geostationary satellite evolution. [Larson and Wertz, 1995]

The question that naturally arises at this point is how much of Argentina will a Geostationary Satellite located at the equatorial plane actually cover. "Coverage" is defined as the ability of the satellite to communicate with a ground station. To answer this question, I will first present some basic definitions: [Larson and Wertz, 1995]

Subsatellite point (SSP): the projection of satellite position over the Earth's surface.

Access Area (AA): the total area that the satellite antenna "sees" at any moment .

Field of view (FOV) or "Footprint": the instantaneous region on the ground being covered. This is driven by the antenna design. In this particular example, we will consider omnidirectional antennas, so we have no restrictions on FOV due to the antenna design.

Swath Width: The angular or linear distance across the access area (Figure 3.1).

Nadir angle of the sensor (η), Grazing angle (ε), Earth Central Angle (λ), and Earth Central Angle to the Horizon (λ_o) can be better understood from Figure 3.1, Figure 3.2, and Figure 3.3. For GEO satellites:

-Grazing angle, ε=0

-Altittude above the Earth's surface, H=35,786 Km

-Radius of the Earth, R_E= 6378 Km

-Swath Width= 2 λmax

-Sinη=cosε/(1+H/R_E)=1/1+35786/6378=0.151266 so η=8.7 Degrees

-λmax= 90-η-ε = 90-8.7= 81.3 degrees

This value tells us that geometrical constraints limit coverage from the equator to 81.3 degrees North or South. Considering the Argentina boundaries are 74 ° W and 52° W, geostationary satellites located from about 7 °E to 133°W can provide the required East-West coverage. Physics keeps us from doing anything about the lack of polar coverage, but we can manage the GEO position that favors our needs, though this is becoming increasingly difficult because GEO is actually crowded over the Atlantic Region.[2]

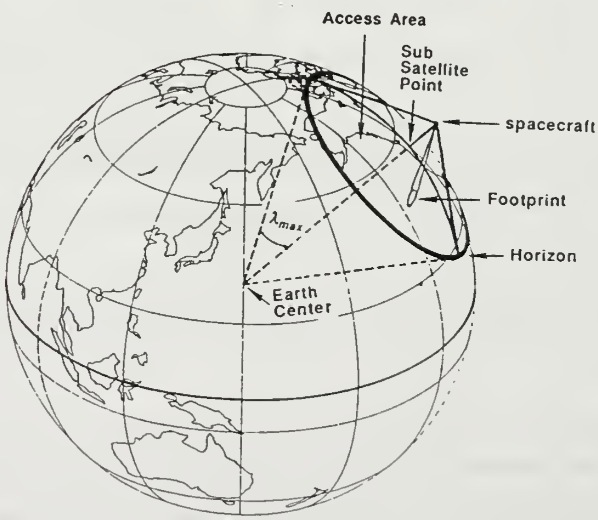

Figure 3.1. Access Area and Footprint [Larson and Wertz, 1995]

[2] The same segment of GEO seems to be the most appropriate for North and South America, so as the number of GEO satellites increases, the probability of getting an optimal position for a new satellite decreases.

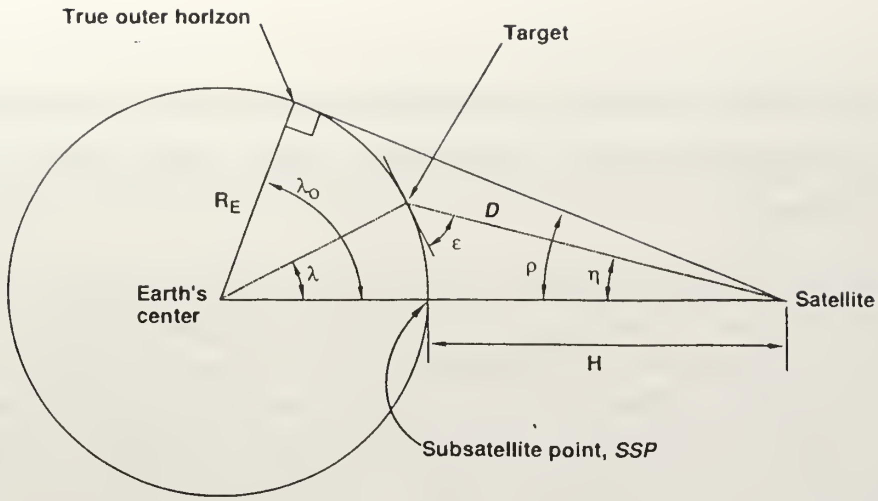

Figure 3.2. Angular relations considered in the coverage problem [Larson and Wertz, 1995]

Figure 3.3. Earth coverage geometry [Larson and Wertz, 1995]

Note that λ is the off ground track angle and $2\lambda_{max}$ is the swath width. P is the ground station.

C. WHAT CIVILIAN SPACE COMMUNICATION SYSTEMS IN GEO COULD BE AVAILABLE FOR ARGENTINE NAVY NOW AND IN THE NEAR FUTURE?

Since the beginning of space commercialization, when INTELSAT I was launched in 1965, the geosynchronous orbit has developed in such way that today it is very difficult to get a position for a satellite in some critical areas. More than 114 communication satellites are now in geosynchronous orbit, excluding those designed exclusively with military purposes. More than 400 have been launched into space since 1964, and today the world is launching about twenty-five every year (twenty-nine during 1996). In some cases, there is no more than one degree of separation between two adjacent satellites. For example, Spacenet 2 (S2) is located at 69° 00' W and Brazilsat B2 is located at 70°00' W.

The countries that currently have satellites in geostationary orbit are the United States, the former Soviet Union, France, Japan, China, India, Luxembourg, Canada, Mexico, Thailand, Brazil, Turkey, Germany, Israel, Sweden, Spain, United Arab Emirates, Australia, Malaysia, South Korea, United Kingdom, Italy, Sweden, Hong Kong and Argentina. Although INTELSAT had the commercial monopoly on satellite communications during the early 1960's and 1970's, the increasing demand for services and the international open sky policies, which encouraged the use of space with peaceful purposes, contributed to the development of a new industry. Military and civil needs also contributed to the growth of this industry and to independent ownership of GEO satellites by individual countries. Countries that are sole owners of GEO satellites are not

necessarily "space capable," some of them just had the money to pay prime contractors to build satellites and the legislation and marketing structure to make profit after the services were established.

Today, twelve organizations operate forty communication satellites that serve North and South America. There are another twenty-three satellites under construction and six new operators waiting to join the list. Table 3.1 summarizes the existing satellites that provide communication services to North and South America, along with those planned for the near future.

D. HOW CAN THE ARGENTINE NAVY USE COMMERCIAL GEO SATELLITES TO SUPPORT NAVAL OPERATIONS?

1. Requirements

Communications required to support the Argentine Navy C^3I structure are not fundamentally different from those required by the U.S. Navy, but the scale may be significantly different.

Our basic operational communication requirements are:

-Naval telecommunications supporting a battle group. That means short-range communications between the battle group members (tactical communications).

-Long-range communications between shore commands and battle groups.

-Strategic submarine communications between the submarine authority and deployed submarines.

Table 3.1. North and South American Geosynchronous Communications Satellites.

System Name	Operator	Launch	Class	Frequency	(Ghz)	Lifetime	Orbit Location
		Date		Uplink	Downlink	Years	(deg. long.)
ACTS	NASA	93	Exp.*	30	20	6	100 W
AMRC 1	American Mobile Radio Corp.	TBD	DARS	6.525-6.725	2.31-2.36	10	99 W
AMRC 2	American Mobile Radio Corp.	TBD	DARS	6.525-6.725	2.31-2.36	10	103 W
AMSC-1	American Mobile Satellite &	95	MSS	1.631-1.66	1.530-1.559	10	101 W
	TMI Communications Canada		FSS	14-14.5	11.7-12.2		
Msat 1	American Mobile Satellite &	96	MSS	1.631-1.66	1.530-1.559	10	106.5 W
	TMI Communications Canada		FSS	14-14.5	11.7-12.2		
AMSC-2	American Mobile Satellite Corp.	TBD	MSS	1.6161.626	1.515-1.525		62 W
AMSC-3	American Mobile Satellite Corp.	TBD	MSS	L &Ku	L &Ku		139 W
Anik C1	Telesat Canada	85	Feeder	14-14.5	11.7-12.2	10	114.9 W
Anik C2	Argentina (Paracomsat)	82	FSS	14-14.5	11.7-12.2	10	72 W
Anik E1	Telesat Canada	91	FSS	5.925-6.425	3.7-4.2	10	111.1 W
			FSS	14-14.5	11.7-12.2		
Anik E2	Telesat Canada	91	FSS	5.925-6.425	3.7-4.2	10	107.3 W
			FSS	14-14.5	11.7-12.2		
Astrolink	Lockheed Martin Telecommun.	TBD	FSS	27-29.25	17.7-19.45	10	97 W
Aurora 2 Satcom	GE Americom	91	FSS	5.925-6.425	3.7-4.2	12	139 W
Brasilsat A1	Hughes	85	FSS	5.925-6.425	3.7-4.2	8	79 W
Brasilsat A2	Embratel Brasil	86	FSS	5.925-6.425	3.7-4.2	8	92 W
Brasilsat B1	Embratel Brasil	94	FSS	5.925-6.425	3.7-4.2	12	70, 65 W
Brasilsat B2	Embratel Brasil	95	FSS	5.925-6.425	3.7-4.2	12	70, 65 W
Brasilsat B3A	Embratel Brasil	97	FSS	5.925-6.425	3.7-4.2	12	65 W
Brasilsat B4	Embratel Brasil	98	FSS	5.925-6.425	3.7-4.2	12	65 W
Cansat KA-1	Canada	2000	FSS	27-29.25	17.7-19.45	20	107.3 W
			FSS	13.75-14.5	11.45-12.2		
Cansat KA-2	Canada	2000	FSS	27-29.25	17.7-19.45	20	111.1 W
			FSS	13.75-14.5	11.45-12.2		
Cansat KA-3	Canada	2000	FSS	27-29.25	17.7-19.45	20	118 W
			FSS	13.75-14.5	11.45-12.2		
Caribstar	WorldSpace	TBD	DARS	20-30	1.462-1.492	TBD	75 W
Celsat	Celsat,inc.	TBD	MSS	1.97-1.99	2.16-2.18	TBD	78 W
Celsat	Celsat,inc.	TBD	MSS	1.97-1.99	2.16-2.18	TBD	89 W
Celsat	Celsat,inc.	TBD	MSS	1.97-1.99	2.16-2.18	TBD	109.2 W
Cyberstar	Loral space and Comm's Ltd.	TBD	FSS	27-29.25	17.7-19.45	12	115 W
DBS-1	Hughes	93	BSS	17.3-17.8	12.2-12.7	12	101.2 W
DBS-2	Hughes	94	BSS	17.3-17.8	12.2-12.7	12	100.7 W
DBS-3	Hughes	95	BSS	17.3-17.8	12.2-12.7	12	157 W
DBSC (EchoStar 3)	EchoStar Com's Corp.	97	BSS	17.3-17.8	12.2-12.7	10	61.5 W
DBSC (EchoStar 4)	EchoStar Com's Corp.	98	BSS	17.3-17.8	12.2-12.7	10	175 W
DSBC	Digital Satellite Broadcasting Corp.	TBD	DARS	7.025-7.075	2.31-2.36	15	101 W
DVS-1	Dominion Video satellite	TBD	BSS	17.3-17.8	12.2-12.7	TBD	61.5 W

System Name	Operator	Launch Dates	Class	Frequency (Ghz) Uplink	Downlink	Lifetime Years	Orbit Location (deg. long.)
DVS-2	Dominion Video satellite	TBD	BSS	17.3-17.8	12.2-12.7	TBD	166 W
EchoStar 1	EchoStar Com's Corp.	95	BSS	17.3-17.8	12.2-12.7	10	119 W
EchoStar 2	EchoStar Com's Corp.	96	BSS	17.3-17.8	12.2-12.7	10	175 W
EchoStar FSS	EchoStar Com's Corp.	TBD	FSS	14-14.5	11.7-12.2	12	83 W
EchoStar Ka	EchoStar Com's Corp.	TBD	FSS	27-29.25	17.7-19.45	12	121 W
Echo-KuX-1	EchoStar Com's Corp.	TBD	FSS	13.75-14.5	11.45-12.2	12 to15	85 W
Echo-KuX-2	EchoStar Com's Corp.	TBD	FSS	13.75-14.5	11.45-12.2	12 to15	91 W
Galaxy 1R (S)	Hughes	94	FSS	5.925-6.425	3.7-4.2	12	133 W
Galaxy 3R	Hughes	95	FSS	5.925-6.425	3.7-4.2	12	95 W
(Latin American Beam)			DTH	14-14.5	11.7-12.2		
Galaxy 4H	Hughes	93	FSS	5.925-6.425	3.7-4.2	13	99 W
			FSS	14-14.5	11.7-12.2		
Galaxy 5	Hughes	92	FSS	5.925-6.425	3.7-4.2	12	125 W
Galaxy 6	Hughes	90	FSS	5.925-6.425	3.7-4.2	10	74 W
Galaxy 7H	Hughes	92	FSS	5.925-6.425	3.7-4.2	13	91 W
			FSS	14-14.5	11.7-12.2		
Galaxy 8I	Hughes	97	DTH	13.75-14.5	11.45-12.2	12 to 15	95 W
Galaxy 9	Hughes	96	FSS	5.925-6.425	3.7-4.2	12	123 W
Galaxy10	Hughes	98	FSS	5.925-6.425	3.7-4.2	12	123 W
			FSS	14-14.5	11.7-12.2		
Galaxy 11	Hughes	98	FSS	TBD	TBD	TBD	TBD
GE Star	GE Americom	TBD	FSS	27-29.25	17.7-19.45	TBD	85, 105 W
Gstar 1	GE Americom	85	FSS	14-14.5	11.7-12.2	15	103 W
Gstar 2	GE Americom	86	FSS	14-14.5	11.7-12.2	15	125 W
Gstar 4	GE Americom	90	FSS	14-14.5	11.7-12.2	15	105 W
Ladybug-1	KaStar Satellite Communications	TBD	FSS	27-29.25	17.7-19.45	10	73 W
Ladybug-2	KaStar Satellite Communications	TBD	FSS	27-29.25	17.7-19.45	10	109.2 W
Loral-1	Loral space & Communications	TBD	FSS	5.925-6.425	3.7-4.2	12	79 W
			FSS	14-14.5	11.7-12.2		
Loral-2	Loral space & Communications	TBD	FSS	5.925-6.425	3.7-4.2	12	129 W
			FSS	14-14.5	11.7-12.2		
Loral Double Ku	Loral space & Communications	TBD	FSS	13.75-14.5	11.45-12.2	12	81 W
Loral Extended C& Ku	Loral space & Communications	TBD	FSS	6.425-6.72	3.4-3.7	12	77 W
			FSS	13.75-14.5	11.45-12.2		
MCI-1	MCI/News Corp.	98	BSS	17.3-17.8	12.2-12.7	TBD	110 W
MCI-2	MCI/News Corp.	99	BSS	17.3-17.8	12.2-12.7	TBD	110 W
Megasat-1	Mexico	TBD	FSS	28.35-30	18.55-20.2	TBD	104 W
Megasat- 2	Mexico	TBD	FSS	28.35-30	18.55-20.2	TBD	85 W
Megasat-3	Mexico	TBD	FSS	28.35-30	18.55-20.2	TBD	95 W
Millenium	Comm. Inc. Motorola Inc.	TBD	FSS	27-29.25	17.7-19.45	10	75 W
Millenium	Comm. Inc. Motorola Inc.	TBD	FSS	27-29.25	17.7-19.45	10	77 W

System Name	Operator	Launch Dates	Class	Frequency (Ghz) Uplink	Downlink	Lifetime Years	Orbit Location (deg. long.)
Millenium	Comm. Inc. Motorola Inc.	TBD	FSS	27-29.25	17.7-19.45	10	87 W
Millenium	Comm. Inc. Motorola Inc.	TBD	FSS	27-29.25	17.7-19.45	10	91 W
Morelos B	Telecomunicaciones de Mexico	85	FSS	5.925-6.425	3.7-4.2	13	116.8 W
			FSS	14-14.5	11.7-12.2		
Morelos-3	Telecomunicaciones de Mexico	98	FSS	5.925-6.425	3.7-4.2	13	116.8 W
			FSS	14-14.5	11.7-12.2		
Morning Star-1	Morning Star Satellite Corp.	TBD	FSS	27-29.25	17.7-19.45	12	147 W
Morning Star-2	Morning Star Satellite Corp.	TBD	FSS	27-29.25	12.2-12.5	12	147 W
Nahuelsat-1	Nahuelsat, Argentina	97	DTH	13.75-14.5	11.45-12.2	14	80 W
Nahuelsat-2	Nahuelsat, Argentina	97	DTH	13.75-14.5	11.45-12.2	14	85 W
Netsat 28	Netsat 28 Co. LLC	TBD	FSS	27-29.25	17.7-19.45	10	95 W
Orion-F4	Orion Network Systems inc.	99	FSS	14-14.5	11.7-12.2	12	135 W
Orion Ka	Orion Network Systems inc.	TBD	FSS	27-29.25	17.7-19.45	13	81 W
Orion Ka	Orion Network Systems inc.	TBD	FSS	27-29.25	17.7-19.45	13	89 W
Orion Ka	Orion Network Systems inc.	TBD	FSS	27-29.25	17.7-19.45	13	127 W
PAS (Ka)	PanAmSat corp.	TBD	FSS	27-29.25	17.7-19.45	TBD	125 W
Primostar	Primosphere LP	TBD	DARS	7.025-7.075	2.31-2.36	10	80 W
Primostar	Primosphere LP	TBD	DARS	7.025-7.075	2.31-2.36	10	110 W
R/L DBS Co,-1	Rainbow/Loral (Ex-Continental)	TBD	BSS	17.3-17.8	12.2-12.7	TBD	61.5 W
R/L DBS Co,-2	Rainbow/Loral (Ex-Continental)	TBD	BSS	17.3-17.8	12.2-12.7	TBD	166 W
Satcom C-1	GE Americom	90	FSS	5.925-6.425	3.7-4.2	10	137 W
Satcom C-3	GE Americom	92	FSS	5.925-6.425	3.7-4.2	12	131 W
Satcom C4	GE Americom	92	FSS	5.925-6.425	3.7-4.2	12	135 W
Satcom K-1	GE Americom	85	FSS	14-14.5	11.7-12.2	10	85 W
Satcom K-2	GE Americom	86	FSS	14-14.5	11.7-12.2	10	81 W
Satellite CD Radio	CD Radio	TBD	DARS	7.035-7.055	2.31-2.36	15	110 W
SBS 4	Hughes	84	FSS	14-14.5	11.7-12.2	9	77 W
SBS 5	Hughes	88	FSS	14-14.5	11.7-12.2	10	123 W
SBS 6	Hughes	90	FSS	14-14.5	11.7-12.2	10	95 W
Solidaridad 1	Telecomunicaciones de Mexico	94	FSS	5.925-6.425	3.7-4.2	14	109.1 W
			FSS	14-14.5	11.7-12.2		
			MSS	1.631-1.660	1.53-1.555		
Solidaridad 2	Telecomunicaciones de Mexico	94	FSS	5.925-6.425	3.7-4.2	14	113 W
			FSS	14-14.5	11.7-12.2		
			MSS	1.631-1.660	1.53-1.555		
Spacenet 2	GE Americom	84	FSS	5.925-6.425	3.7-4.2	10	69 W
Spacenet 3	GE Americom	88	FSS	5.925-6.425	3.7-4.2	10	87 W
Spacenet 4	GE Americom	91	FSS	5.925-6.425	3.7-4.2	10	101 W
Telstar 303	Loral Skynet	85	FSS	5.925-6.425	3.7-4.2	10	97 W
Telstar 402R	Loral Skynet	95	FSS	5.925-6.425	3.7-4.2	10	89 W
			FSS	14-14.5	11.7-12.2		

System Name	Operator	Launch Dates	Class	Frequency (Ghz) Uplink	Downlink	Lifetime Years	Orbit Location (deg. long.)
Telstar 5	Loral Skynet	97	FSS	5.925-6.425	3.7-4.2	15	97 W
Telstar 6	Loral Skynet	98	FSS	5.925-6.425	3.7-4.2	15	93 W
Telstar 7	Loral Skynet	99	FSS	5.925-6.425	3.7-4.2	15	69 W
Tempo	Tempo Satellite inc.	97	BSS	17.3-17.8	12.2-12.7	10	119 W
Tempo	Tempo Satellite inc.	97	BSS	17.3-17.8	12.2-12.7	10	166 W
USSB	U.S. SatelliteBroadcasting	93	BSS	17.3-17.8	12.2-12.7	TBD	101 W
USSB	U.S. SatelliteBroadcasting	TBD	BSS	17.3-17.8	12.2-12.7	TBD	110 W
USSB	U.S. SatelliteBroadcasting	TBD	BSS	17.3-17.8	12.2-12.7	TBD	148 W
VisionStar	Visionstar Inc.	TBD	FSS	27-29.25	17.7-19.45	12	113 W
VoiceSpan	AT&T	TBD	FSS	27-29.25	17.7-19.45	12	93 W
VoiceSpan	AT&T	TBD	FSS	27-29.25	17.7-19.45	12	103 W

***Abbreviations:**

BSS-Broadcasting Satellite Service
DARS-Digital Audio Radio service
DTH- Direct-to-home (TV)
Exp-Experimental
FSS-Fixed Satellite Services
MSS- Mobile Satellite Services
TBD-To be determined

Definitions:

Uplink frequencies are used to transmit signals from Earth stations to the satellite. Downlink frequencies are used by the satellite to retransmit signals back to Earth.

Source: Space News, March 3-9, 1997

Ultra High Frequency (UHF) and High Frequency (HF) circuits provide most of the U.S. Navy's tactical communications. It supports Command and Control functions, dissemination and distribution of sensor data, and control of combat and weapon systems. The range established by the U.S. Navy for this type of communications is 220 nautical miles. To allow these UHF ranges military satellites are used. This tactical conception is based in the U.S. weapon's range and defensive capability. [Kim, 1995]

Although Argentine Navy tactical communications range is less than 110 nautical miles, ships operating beyond the horizon still require HF systems to communicate. We would like to use UHF frequencies all the time because they are more difficult to be listened by third parties, unless they were close enough to be shot, but we have to suffer the absence of military communication satellites.

Argentine Navy long-range communications are normally limited to the South Atlantic Ocean, and the distances involved are 500 miles or less, rather than the 400 to 6000 nautical miles considered by the U.S. Navy.

In the particular case of Argentine ships deployed as a part of an international force, communication with Argentine Navy shore commands is basically administrative, and INMARSAT has, until now, been the most appropriate way to achieve it. In these situations, tactical communication with international forces has been more complicated and has sometimes required special equipment provided by the U.S. Navy.

For the U.S. Navy, which has a variety of technical means to establish secure tactical and long-range communications, commercial satellites would only be appropriate

for backup or administrative functions. In our case, not having military satellites implies that the only way to add a new capability,such as a satellite link, is to use what already exists.

Suppose the hypothetical situation in which the Officer in Tactical Command (OTC) needs to change the orders to the units deployed just 200 nautical miles from the flag ship. In this situation, the U.S. Navy communications officer probably uses a UHF circuit supported by one of the different FLSATCOM or LEASAT satellites, keeping an HF circuit as a backup. The Argentine communications officer must use an HF circuit, with another HF circuit as a backup. Could a commercial GEO satellite be a feasible alternative to increase our tactical capability? If it were feasible, should this new band be used instead of, or as a backup to the primary HF circuit?

I will consider INTELSAT and INMARSAT a representative examples of satellite systems that the Argentine Navy can use for military purposes, because Argentina is already using these systems, though not for tactical communications, and because both of them have been used before in military operations (for example, during and after the Persian Gulf War). Moreover, I think that the different series of INTELSAT and INMARSAT are representative of their classes and, in both cases we can find the essential capabilities found in most other GEO satellites offered in the commercial market.

2. INMARSAT

From 1972 to 1979, the Intergovernmental Maritime Organization (IMO), began a project to create an international maritime satellite system. In 1979, twenty-six nations

established the initial agreements and created the International Maritime Satellite Organization (INMARSAT). In 1982 INMARSAT introduced a new capability for marine communications by providing satellite voice service. The first standard terminals, known as Standard-A (INMARSAT-A), were expensive and so was the service. In fact, the cost is still so high that the system must be used sparingly, compared to standard telephone systems. When installed on a warship, INMARSAT requires special considerations. The electronic organization of the ship can be altered by this new system and sometimes there is no room for a new antenna. In the past two decades, it was the only service able to provide global coverage, including the most isolated areas and the middle of the oceans. [Lodge, 1991] Today, INMARSAT has evolved in order to satisfy the new markets and customer needs and to prepare for the competition from proposed LEO satellites, which promise coverage of the entire globe.

INMARSAT is comprised of four segments: Satellites, which can be owned or leased; Coast Earth Stations (CES), which are operated by INMARSAT owners and deployed around the world; Ship Earth Stations (SES), which are owned and operated by ship-owners; and the Primary Control Facility for Tracking Telemetry and Control (TT&C), located in London, England. The only part that users can control is the SES. There are many types of Ship Earth Stations to choose from:

-INMARSAT-A: Having a one meter diameter parabolic antenna and a medium size terminal, it is capable of providing facsimile and data transmission up to 9.6 Kbps, along with one analog voice channel, which can also be used as a single 56 Kbps data rate

channel. The complete INMARSAT-A terminal can be carried in one or two suitcases. During the Persian Gulf War, a variety participants, including Kuwaiti resistance fighters, CNN crews, U.S. forces and others used more than 150 "one suitcase" INMARSAT-A. These terminals were also used to transmit electronic photos at a 56 Kbps data rate. [Comparetto, 1993]

-INMARSAT-B: The digital successor of INMARSAT-A. The terminal is similar to INMARSAT-A, but improved. It is able to provide direct-dial telephone, facsimile, and TELEX. Data can be sent at 64 Kbps synchronous High Speed Data (HSD), or at 9.6 Kbps asynchronous standard.[3]

-INMARSAT-C: This terminal can store and forward digital data (electronic mail, TELEX and packet-switched data networks) at a rate of 600 bps but will not provide voice communication. The terminal fits in a suitcase and requires a hemispheric non-pointing antenna, about a half meter in diameter.[Comparetto, 1993]

-INMARSAT-M: This version is designed for a high degree of commonality with the INMARSAT-B system in order to minimize mobile equipment cost and make the best possible use of the satellite channel resources and land earth stations hardware. INMARSAT-M terminals are smaller than INMARSAT-A and INMARSAT-B terminals, in some cases smaller than a briefcase. The terminal requires a half meter diameter parabolic antenna and demands less bandwidth and satellite power. It can provide facsimile

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[3] The physical layer typically operates at 9.6 Kbps. Each character consists of eight bits transmitted asynchronously (with start and stop bits). This results in an overhead of 25% without using a parity bit, and 45% using a parity bit. Synchronous transmission uses special frames and considerably reduces the overhead.

and data services up to 2.4 Kbps and one digital voice channel at 6.4 Kbps. [Feldman, 1996]

I think that INMARSAT-B is the most appropriate version for Argentine Navy purposes, because it can integrate voice and data and improves the use of power and bandwidth, thereby lowering the cost. (INMARSAT-A is $6.25 per minute, INMARSAT-B is $3.00 per minute)

Today, INMARSAT has six satellites in orbit, which cover the entire earth except for the polar regions. Table 3.2 provides some characteristics of the INMARSAT constellation.

Table 3.2. INMARSAT Satellites.

Satellite Denomination	Launch Date	Position	Frequency
INMARSAT 2F2	3/8/91	55.5 W	L-Band & C-Band
INMARSAT 2F3	12/16/91	65.0 E	L-Band & C-Band
INMARSAT 2F4	4/15/92	54.0 W	L-Band & C-Band
INMARSAT 3F1	4/3/96	64.0 E	L-Band & C-Band
INMARSAT 3F2	9/6/96	16.0 W	L-Band & C-Band
INMARSAT 3F3	12/18/96	178.0 W	L-Band & C-Band

L-Band:1.6 to 1.5 Ghz

C-Band:6.4 to 3.6 Ghz

Capacity: 250 duplex (two way communication) voice channels

Lifetime: 10 years

3. INTELSAT

INTELSAT is a cooperative, non-profit organization having more than 135 member nations. It is operated commercially; every user must pay for its services. The charges vary depending on the type of service. It is possible to lease the transponder for

months, lease a given number of hours in a given period of months, or just request a special service (for example an international video conference for six hours). The service is not restricted to the member nations. Any nation can use it for a fee. INTELSAT is composed of three segments: satellites, owned and operated by the organization; a control center, also governed by the organization; and ground terminals.

The INTELSAT constellation currently has twenty-four satellites, all in geostationary equatorial orbit, which is divided into four regions: Atlantic Ocean, Indian Ocean, Asia Pacific, and Pacific Ocean. The number and distribution of the satellites assure worldwide coverage up to 70 degrees of latitude. The INTELSAT satellites were developed by different contractors and are located in relation to user needs. Figure 3.4 and Table 3.3 summarize the distribution and characteristics of INTELSAT satellites.

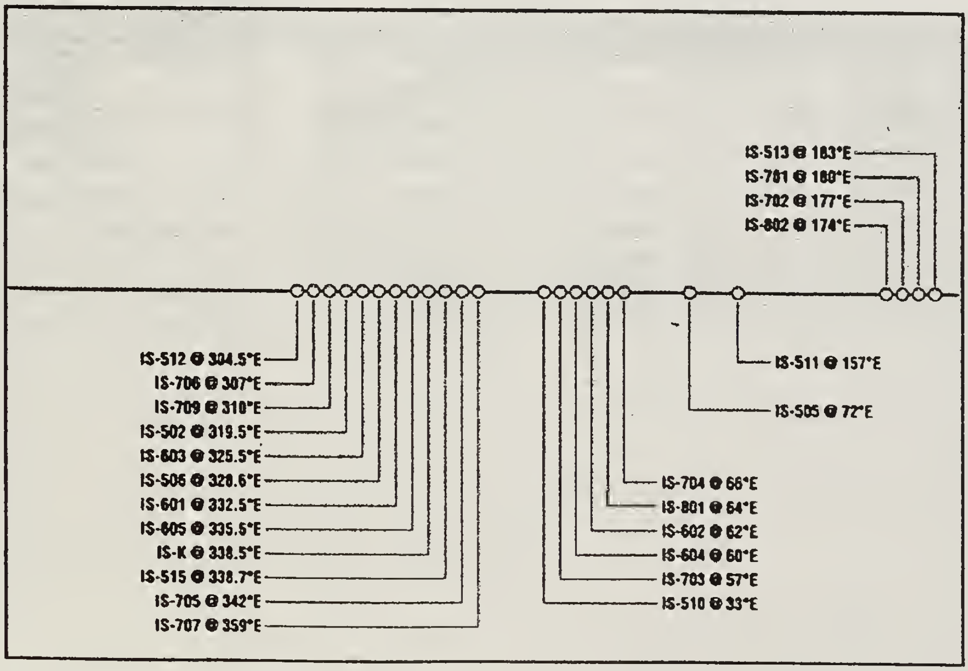

Figure 3.4. INTELSAT Global Distribution [INTELSAT, 1997].

Table 3.3. INTELSAT Satellites [INTELSAT, 1997].

Satellite Denomination	Position deg. long.	Frequency	Capacity	Lifetime
INTELSAT 502	319.5 E	C-Band[4] (21) & Ku-Band[5] (4)[6]	12000 two-way telephone circuits and 2 TV channels	7 years
INTELSAT 505	72.0 E	C-Band (21) & Ku-Band (4)		7 years
INTELSAT 506	328.6 E	C-Band (21) & Ku-Band (4)		7 years
INTELSAT 510	33.0 E	C-Band (26) & Ku-Band (6)	15000 two-way telephone circuits and 2 TV channels	7 years
INTELSAT 511	157.0 E	C-Band (26) & Ku-Band (6)		7 years
INTELSAT 512	304.5 E	C-Band (26) & Ku-Band (6)		7 years
INTELSAT 513	183.0 E	C-Band (26) & Ku-Band (6)		7 years
INTELSAT 515	338.7 E	C-Band (26) & Ku-Band (6)		7 years
INTELSAT 601	332.5 E	C-Band (38) & Ku-Band (10)	24000 two-way telephone circuits and 3 TV channels	13 years
INTELSAT 602	62.0 E	C-Band (38) & Ku-Band (10)		13 years
INTELSAT 603	325.5 E	C-Band (38) & Ku-Band (10)		13 years
INTELSAT 604	60.0 E	C-Band (38) & Ku-Band (10)		13 years
INTELSAT 605	335.5 E	C-Band (38) & Ku-Band (10)		13 years
INTELSAT 701	180.0 E	C-Band (26) & Ku-Band (10)	184000 two-way telephone circuits and three TV channels; up to 90,000 two way telephone circ. using DCME [7]	10 years
INTELSAT 702	177.0 E	C-Band (26) & Ku-Band (10)		10 years
INTELSAT 703	57.0 E	C-Band (26) & Ku-Band (10)		10 years
INTELSAT 704	66.0 E	C-Band (26) & Ku-Band (10)	22,500 two-way telephone circuits and 3 TV channels; up to 112,500 two way telephone circ. using DCME	10 years
INTELSAT 705	342.0 E	C-Band (26) & Ku-Band (10)		10 years
INTELSAT 706	307.0 E	C-Band (26) & Ku-Band (10)		10 years
INTELSAT 707	359.0 E	C-Band (26) & Ku-Band (10)		10 years
INTELSAT 709	310.0 E	C-Band (26) & Ku-Band (10)		10 years
INTELSAT 801	64.0 E	C-Band (38) & Ku-Band (06)		14 years
INTELSAT 802	174.0 E	C-Band (38) & Ku-Band (06)		14 years
INTELSAT K-TV	338.5 E	Ku Band (30 x 36 Mhz)	DTH [8]	-

[4] C-Band: Frequency band between 4-8 Ghz.
[5] Ku-Band: Frequency band between 12-18 Ghz
[6] The number of transponders in the given band is in parentheses.
[7] DCME: Digital Circuit Multiplication Equipment
[8] DTH: Direct-to-home (Television)

INTELSAT uses six Telemetry, Tracking and Control (TT&C) stations located around the world, which are all connected to the INTELSAT Operations Center in Washington D.C. [Zoppa, 1994]. INTELSAT provides telephony, data transfer, facsimile, television and teleconferencing. The required antennas are about 3.5 to 18 m in diameter and use international Standards A, B or C.

Standard A was used with a large antenna (15 to 18 m in diameter) because the ground segment had to receive low power signals from the satellite. The "A" terminals are medium or high capacity, with at least 24 voice circuits each. The operational frequency is C-Band.

Standard B arrived when technology enabled satellites to have more radiated power, so the ground stations are smaller than those used for Standard A. The objective was to provide lower cost terminals. Of course, the simple terminals have reduced capacity (less than 24 voice circuits). The antenna varies from 10 to 12 meters in diameter.

Standard C first came with INTELSAT V. This Standard operates in the Ku band, and it is only used by Nations with large (high capacity and many circuits) communication requirements. Some Standard C terminals use dual antennas separated by 10 to 20 miles in order to overcome rain degradation, which is significant at Ku-Band frequencies. The antenna varies from 12 to 15 meters in diameter.

None of the antennas just mentioned can be used on board ships They were designed to point toward a GEO satellite and transmit with high power. The

implementation of the Challenge Athena Program, which used an 2.4 meter diameter antenna aboard the USS George Washington, revolutionized the U.S. Navy communications by allowing high data rate communications (voice, data and video) through the INTELSAT satellites. From the military point of view, the use of civilian assets with tactical or operational purposes is, at first, difficult to visualize. Security prejudices normally arises in the minds of our Commander Officers because they think that everyone is listening in on public systems. In fact, INTELSAT communications can be intercepted as easily as HF communications.

From the beginning, the Challenge Athena program, which I will explain later, changed the U.S. Navy thinking about civilian satellite communications, and the Navy is now looking for more such successful and economic methods of communication.

It would be virtually impossible to develop a dedicated Argentine Military Satellite Program. It would cost at least 300 million dollars. Political conditions are not favorable for committing that amount of money to a program that surely would not be a high priority for politicians. INTELSAT (and others) leases space segment capacity in bandwidth increments of 9, 18, 36, 54 or 72 Mhz. In some cases, when available, the user can buy a transponder instead of leasing bandwidth. This provides an interesting option, because the purchaser owns the transponder, which allows unlimited use of the entire transponder instead of just a portion, though INTELSAT provides satellite control and maintenance. [Comparetto, 1993]

Argentina is ranked seventh among 139 countries that have invested in INTELSAT (with an investment 2.990119 %, of which 2.346509 % belongs to the "Comision Nacional de Telecomunicaciones" and the rest to small companies). We already have more than thirty-six INTELSAT Earth stations and the provision of all INTELSAT commercial services, so we can consider using the commercial technology to support our military structure. Of course, it would not be easy to implement. The U.S. Navy is just now establishing the concept.

4. **Challenge Athena as an Example of Implementation** [Shaw, 1995].

U.S. Chief of Naval Operations (CNO) Special Project Challenge Athena (CA) is a good example of using civilian satellite communications technology for military purposes. However, we must realize that U.S. Navy's global communication objectives are different from ours. CA was created to fulfill specific naval operational requirements. During the Desert Storm and Desert Shield Operations (1990-1991), the U.S. Navy found that it had trouble sending large volumes of information to ships at sea in a timely manner. For example, some printed information that could have helped the U.S. Ranger (CV-61) was stored in Saudi Arabia, waiting for higher priority messages to be delivered. The Ranger received the information after the cease fire. The Navy realized it needed to increase its high data rate communications capability, because existing military satellites (for example, the Defense Satellite Communications System) were unable to satisfy all its needs.

Challenge Athena was started in 1991 by Lieutenant Commander John Hearing in his Naval Postgraduate School (NPS) thesis *On Target-Imagery Support to Strike*

Warfare. He studied the problem of establishing high data rate communications to deployed Navy ships for the transmission of digital imagery. Because the military satellites available at that time did not have the capacity to support the required data rate, he concentrated his attention on commercial satellites.

While working in the Space Systems Division as a member of the Chief of Naval Operations staff, he convinced the other members to use commercial satellites to fulfill requirements not achievable with the bandwidth restrictions of existing military systems. The program began as Challenge Athena Phase I, which demonstrated the feasibility of using civilian satellites to provide a simplex link to an aircraft carrier.[9]

The test was successfully implemented on the USS George Washington during August, September and October of 1992. The installation consisted of an off-the-shelf small aperture antenna, commercial satellite communications transceivers, and U.S. national imagery dissemination equipment (Prototype Joint Service Intelligence Processing System (JSIPS-N) and a National Input Segment (NIS) imagery processor). The aircraft carrier sent requirements to the supporting shore station and received the appropriate information in a timely manner and in sufficient quality to satisfy the end users. In a paper *Challenge Athena: The Complete Ticket At The Table of Jointness*, describing CA operation, the author, LCDR James J. Shaw said:

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[9] Simplex: One way communication, only one can talk at a time.

The Requested images were encrypted, multiplexed with other services at the communications hub, sent over land line to a commercial Gateway Earth Station (GES) with its 90 ft (30m) antenna (Standard A), transmitted up to an INTELSAT commercial satellite, and broadcast on a global C-Band (4-6 GHz) transponder to the ship.

Because it demonstrated its feasibility during the first phase, the project rapidly received DoD support. The Navy and DoD decided the program should be improved and expanded. The second phase, CHALLENGE ATHENA Phase II (CA II), demonstrated the feasibility of using full duplex (two-way communication, simultaneously) commercial communications with deployed surface units. The three main objectives during this phase were :

-Deliver large volumes of imagery to deployed warfighters

-Evaluate commercial satellite communications in sea operations

-Prove the feasibility of user-control of communications for extended periods of time.

CHALLENGE ATHENA Phase II supported the USS George Washington Battle Group for six months during an Atlantic Ocean, Mediterranean Sea and Persian Gulf deployment. The satellite service provided a 1.544 Mbps duplex link.[10] Its most important

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[10] 1.544 Mbps is equivalent to transmitting one standard high density computer floppy disk full of information per second.

feature was that it integrated military and civil communications, and the ship had control of the multiplexing equipment, so the ship operators could configure onboard and shore multiplexers, mix and match services, prioritize services and allocate bandwidth as a function of requirements. The staff of the USS George Washington labeled this demonstration a resounding success.

CHALLENGE ATHENA Phase II provided:

-Intelligence information with a high data rate of 1.544 Mbps, which allowed to support U.S. imagery dissemination systems. Today some weapons can locate and strike their targets using this information.

-Multiple-line telephone connectivity, for official business and personnel communications.

-Video Teleconferencing (VTC)

-Video Teletraining (VTT) for remote training.

-Video Telemedicine(VTmed)

The Challenge Athena Phase III will continue improving the capability to extend commercial wide-band satellite communications to deployed forces. Its goal is to expand this capability to the major possible number of ships including cruisers and destroyers.

5. **Legal concerns in the use of INTELSAT and INMARSAT for military purposes** [Comparetto, 1993].

INTELSAT and INMARSAT are similar in that both provide services established by international treaties, both are carried out by international organizations and both are based on the criteria that communications should be available to all nations. For this reason, the organizations have restrictions on using them for military purposes. Gary Comparetto, a communication specialist from The Mitre Corporation, made an interesting study named *On the use of INTELSAT and INMARSAT to support DoD communication requirements*. In one part of his study, he analyzed how restricted the systems were. It showed that restrictions were not clear enough to avoid being interpreted by the users in the convenient way. This study also showed how the U.S. military agencies found legal support for using these systems extensively. It seems clear to me that the U.S. has set a precedent for other nations to use commercial communication satellites for military purposes.

Comparetto, in his study of INTELSAT, remarked that the only place in which military applications are mentioned in the INTELSAT Agreement is in Article III, the part that talks about the space segment. The agreement says: "[INTELSAT satellites] also can be utilized for the purpose of **specialized telecommunications services**, either international or domestic, other than for military purposes." Later, he defines **specialized communication services** as "... telecommunication services which can be provided by satellite, other than those defined in paragraph (k) of this article, including but not limited

to, radio navigation services, broadcasting satellite services for reception by the general public, space research services, meteorological services, and earth resource services..." Comparetto explained that "**specialized communication services**" require special hardware that normally is supported by the same satellite bus, but functions separately from the rest of payload. Because INTELSAT does not offer such a service, there is no problem in using the standard transponders, no matter how they are used.

Summarizing this point, the U.S. interpretation is that the only restriction is to use "**specialized communication services.**" INTELSAT does not have **"specialized communication services,"** so there is no restriction at all.

With respect to INMARSAT, the situation is more difficult to interpret. The clause in Article 3(3) of the INMARSAT Convention says "The organization shall act exclusively for peaceful purposes." This expression has had different and controversial interpretations. In a letter from Dr. Von Noorden, legal advisor for INMARSAT (1987), to COMSAT, after some evaluation of the Convention Interpretations, he concludes:

> *1. It is consistent with the INMARSAT Convention Article 3(3) for INMARSAT to commission Ship Earth Station (SES) on warships and naval auxiliary vessels, and*
>
> *2. If the vessel becomes involved in any armed conflict, the SES should only be used for distress and safety communications and other purposes recognized by international humanitarian law.*

The point of view supported by the U.S. Navy is different.

In January of 1991, the Deputy Assistant Judge Advocate General of the Navy responded to a CNO request about INMARSAT:

> *We conclude that U.S. Navy units may use INMARSAT terminals in support of armed conflict consistent with the UNSC [United Nations Security Council] resolutions enacted during the current Middle East crisis.*

At that time, the U.S. Navy interpreted "peaceful purposes" as:

> *This term [i.e., peaceful purposes] is not defined and its negotiating history does not suggest a specific meaning. Under such a reading, 'peaceful purposes' should be given the meaning that has been accorded under the law relating to outer space activities. Under such a reading 'peaceful purposes' does not exclude military activities so long as those activities are consistent with the United Nations (UN) Charter.*

The clearest example is that the United Kingdom used Ship Earth Stations during Malvinas War and Iraq used them during the Iran-Iraq War. No mechanism was used to enforce the INMARSAT Convention. Another fact is that during Desert Storm Operation, the Coalition Naval and ground forces used more than 150 INMARSAT terminals. In the future, the U.S. Air Force and Army will be interested in other services recently implemented by INMARSAT.

6. Argentine Implementation

From a technical point of view, both INMARSAT (L Band) or INTELSAT (C and Ku Bands), as demonstrated, are feasible to be used by the Argentine Navy. Although, installing 2.4 meter diameter antennas on Argentine ships could be difficult, if not impossible. Challenge Athena was ideally suited to a navy that continuously conducts worldwide operations with thousands of people working at sea for long periods of time (normally more than six months), frequent telemedicine needs, personal needs, requirements for large amounts of information transfer, and weapons that take advantage of this information. U.S. naval operations require billions of dollars per year, not only for maintenance and operating costs, but also for the research and development of the programs created to improve warfighting capability.

The Argentine Navy is basically directed to provide national defense and take part in international missions. We must limit our consideration to a modest communication infrastructure based on commercial satellites, or on a single commercial satellite in the appropriated GEO position. I believe that one leased transponder can provide enough bandwidth to satisfy the Argentine Navy demand and contribute to satisfying requirements of other branches of the military forces.

CHALLENGE ATHENA combined a portion of the military architecture with commercial satellites. Messages were encrypted at each end of the communications link; bulk encryption of the entire circuit was not used. We would need to add compatible

encryption devices in the same manner, if we wanted to take full advantage of commercial systems.

Cost is the limiting factor for the Argentine Navy. Although a concept based on CHALLENGE ATHENA Phase II would be cheaper than other candidate systems, it still cost $3.5 Million during the six month period of operation on the USS George Washington. The U.S. Navy saved million of dollars by using this system instead of INMARSAT. During the six month deployment, Naval personnel made 17,400 hours of official telephone calls, which would have cost $6.525 million dollars using INMARSAT.[11] I believe that this amount is much more than we need to operate the Argentine Navy fleet for an entire year. For our Navy this cost is significant, and we need to study in detail the real cost-benefit of implementing a system like CA II.

Table 3.4 shows comparative costs for the CA II, with respect to INMARSAT. There are some data missing from this table. We know the cost of INMARSAT services ($6.25 /min. or 65.0 cents/KB), because it is publicly advertised, but we must accept the given cost of CA II (0.3 cents/KB) without knowing exactly how it was computed. Keep in mind that this low cost per minute is only valid for the scale of CA II operations.

From the installation point of view, INMARSAT appears more reasonable because it can be used by either big or small ships. The 1 meter diameter INMARSAT antenna is less limiting than the 2.4 meter diameter INTELSAT antenna. The cost of an INMARSAT-A terminal ranges from $30,000 to $55,000, but the cost of an

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[11] Note that 17,400 hours of official calls in 180 days represents an average of four telephone lines working continuously (180 days x 24 hours/day- telephone line x 4 telephone lines= 17,280 hours).

INMARSAT-C terminal is less than $5,000 [Comparetto, 1993]. Table 3.4 gives a comparison of costs for INMARSAT and CHALLENGE ATHENA Phase II.

Table 3.4. Cost Comparison Challenge Athena and INMARSAT [Shaw, 1995]

NON-RECURRING COSTS FOR CHALLENGE ATHENA II:	
SHIPBOARD ANTENNA	$250,000
SHIPBOARD HARDWARE	$92,000
INSTALLATION/INTEGRATION	$300,000
TOTAL NON-RECURRING	$642,000
RECURRING COSTS FOR COMMERCIAL SATELLITE COMMUNICATIONS:	
SATELLITE TRANSPONDER LEASE (GLOBAL, C-BAND, 1544 KILOBITS/SECOND)	$123,000/MONTH
GATEWAY EARTH STATION/LANDLINE COSTS	$85,000/MONTH
TOTAL RECURRING	$208,000/MONTH
(INMARSAT RECURRING COSTS FOR DEPLOYING CV/CVN	$130,000/MONTH)
CHALLENGE ATHENA COST PER KILOBIT-MINUTE:	0.3 CENTS/KB
INMARSAT SERVICE COST PER KILOBIT-MINUTE:	
INMARSAT-A 9.6 KBPS @ $6.25/MIN:	65.0 CENTS/KB
INMARSAT-A 56 KBPS @ $12.00/MIN:	21.5 CENTS/KB
INMARSAT-B 16 KBPS @ $3.00/MIN:	19.0 CENTS/KB

Operationally speaking, INTELSAT (0.3 cents/KB) was cheaper than INMARSAT (65.0 cents/KB) for the U.S. Navy, but the computation was based on continuous and intensive use during the six month period (in addition to the 17,400 hours of official telephone calls, 6500 images were received), so the lease of the transponder was justified. Although, in the long run we will need more throughput (Kbps) to adequately use the technological capabilities commercially offered today. For example, the internet is barely used in Argentina, but is already a working tool on board U.S. Navy ships. I believe that among the candidate GEO satellites, INMARSAT will remain the most appropriate to our needs, though we will also need to consider other, more achievable options like LEO satellite services (to be discussed in the next chapter).

E. BENEFITS AND DISADVANTAGES OF USING GEO COMMERCIAL SATELLITES

1. Benefits

a. Reduced cost

GEO satellite systems are already established, so we don't need to spend significant amounts of money on research and development. We can buy what we need and use it, which means that the Argentine Navy will only need to buy the ship terminals and lease the satellite circuits. Even with implementation and training costs, the option will be always cheaper than developing a dedicated GEO satellite military system ourselves.

b. Increasing Capability

We can achieve interesting new capabilities, which would be very useful when operational needs demand more exchange of information or when traditional communication channels are saturated or unable to provide service. Commercial C, Ku and L bands could supplement our military communications structure. This capabilities include :

-High data rate transmission. INTELSAT can provide data rate of 1.544 Mbps, INMARSAT can provide up to 56 Kbps.[12]

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[12] 1.544 Mbps can be seen as the transmission of one $3^{1/2}$ computer floppy disk full of information per second. Using INMARSAT it will take 26 seconds to transmit it.

-Video Conference. This feature can considerably increase our the C^3I/C^4I capability. No other satellite system has been able to provide it until now.

-Telephone connectivity. INMARSAT already provides telephone services, but INTELSAT may provide a better service with less recurring costs.

c. Experience

Before developing the first Fleet Satellite Communication (FLEETSATCOM) constellation, the U.S. Navy gained experience using "Gapfiller," a UHF transponder added to the MARISAT satellite. Similarly, our Navy could use commercial circuits to gain experience about how to better use satellites for communications.

d. Coverage

Only one satellite could provide coverage to the entire anticipated area of operation. Figure 3.5 shows how the coverage can be from Argentina to the coast of South Africa. The elevation angle (mentioned as 5 "Degree Elevation and 18 Degree Elevation" in the figure) is the angle formed between the horizon of the ground station and the satellite line of sight. The attenuation that the signal suffers through its path is strong function of the elevation angle. A rain cell exists as an atmospheric volume which is wider than it is high therefore, low elevation angles force the radio signal to pass through a

greater thickness of rainfall. As a consequence, more power is required to satisfy the Link Budget Equation.[13] [Elbert, 1987]

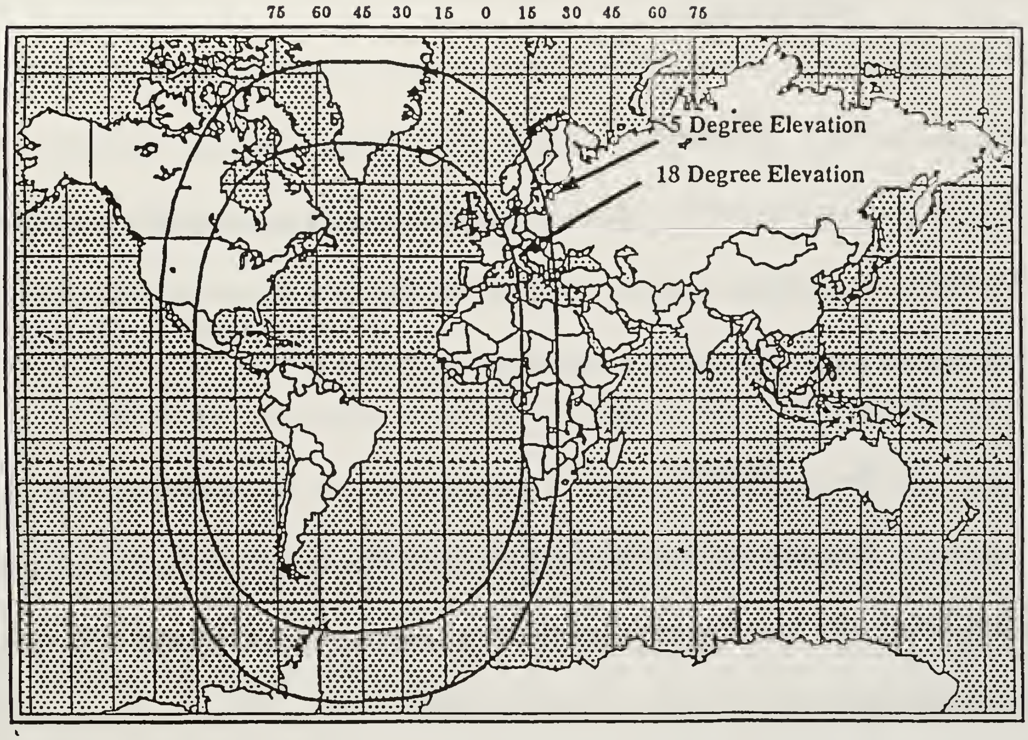

Figure 3.5. Coverage provided by an INTELSAT satellite located at 50 degrees west longitude.

e. U.S. Compatibility

I believe that the U.S. Navy will keep using improved versions of CHALLENGE ATHENA to provide communication circuits that require less protection

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[13] Link budget Equation is used in communication engineering to determine the required power for ground station and satellite transmitters.

than those used for tactical purposes, so it could eventually be the appropriate technical means to be administratively linked during International Operations.

2. Disadvantages

a. Reliability

Because GEO commercial satellites have a commercial architecture, they do not have anti-jamming capability. Commercial satellites do not have countermeasures, so their signals can be affected by even low power jammers.

b. Security

The ship terminals have a high probability of detection and interception, so they are vulnerable to undesired monitoring. Encryption systems on each end of the communications may improve this situation somewhat.

c. Interference

C-band is especially more susceptible to electromagnetic interference from other combat systems, which could be a very important factor when all of our capabilities are needed and some particular equipment must be turned off to allow communications equipment to operate. Apparently, the H.M.S. Sheffield experienced this interference when it failed to pick up the Exocet missile that finally sunk it.[Zoppa. 1994] Communications in Ku-Band frequencies are extremely vulnerable to rain attenuation.

d. Antenna location

The antennas installed on board ships require stabilization in order to continuously track the GEO satellites. Where to install a new on board antenna is always a challenge to the engineer. Installing either an INMARSAT antenna or a stabilized 2.4 m diameter INTELSAT antenna in medium size ships is a big problem; shadow areas and ship-generated interferences must be carefully considered.

e. Time required

The formal administrative process to lease or buy a transponder requires significant time depending on the requirements. The U.S. government can lease a transponder in as little as 20 days. However, the standard procedure to purchase an INTELSAT transponder takes about 230 days assuming that one is available. Transponders are normally leased or purchased five to seven years in advance, so the decision to establish a system centered around a leased or purchased transponder should be made with these lead time in mind.

f. Availability

When leasing time on a transponder or just a portion of the transponder, we must compete with civilian users. Our request should be made in advance and it is not certain that the circuits will be available. To avoid this problem, at least one dedicated transponder would be needed. To reduce cost, it could be shared with other Argentine military forces or government agencies.

F. SUMMARY

Geostationary satellites can be used by the Argentine Navy to increase communication capabilities. The existing technology can provide the required equipment, and the satellites are available in the necessary quantity, along with the orbital positions to satisfy our needs. As was demonstrated during the Persian Gulf War, no legal issues were raised regarding the use of commercial satellites for military purposes. The GEO satellite systems could be used in place of HF circuits for tactical purposes taking some precautions to reduce its vulnerability and remembering that HF circuits are also vulnerable.

We will need to conduct testing before attempting to answer the question of whether HF circuits should be used as the primary or backup communication system, when using a commercial system. It appears that no commercial space system can fulfill all of our requirements. In the particular case of the U.S. Navy, after the exploitation and use of military satellite systems (UHF-SHF-EHF) that relegated the HF circuits to a backup function, they reconsidered the use of improved HF circuits pointing to anti-jamm, low probability of intercept, and higher data rate capabilities, as a primary system. [Kim, 1995]

IV. COMMUNICATION SATELLITES IN LOW EARTH ORBIT (LEO)

A. INTRODUCTION

Historically, the first satellites launched to the space were located in low earth orbits. At that time, the serious limitations established by the launch vehicles justified it. When the first INTELSAT satellite was launched in 1965, the domination of satellite communications by GEO satellites really began. Today, GEO satellites are prevalent in the communications arena, but new ideas are advancing. The need for improvements, particularly in the area of mobile satellite communications (which INMARSAT dominated since the 1980's); the ongoing saturation of the geostationary orbit; the need for cost reduction in the final product (cost of the user equipment and cost per minute of use); and the technological advances made by the satellite developers are some of the reasons why Low Earth Orbit Satellites (LEO's) are gaining a place in communications.

In 1992, the World Administrative Radio Conference (WARC-92) on the International Telecommunications Union (ITU) considered the issue of frequency allocation for non-GEO satellites. The WARC-92 assigned the 1610-1626.6 Mhz (L-Band) and 2483.5- 2500 Mhz (S-Band) slots to big LEO services on worldwide basis. Small LEO's were restricted to VHF/UHF bands below 1 Ghz. The main difference between big and small LEO's is that small LEO's are unable to transmit voice because of the narrow bandwidth, so these systems are limited to data transmission services, while big LEO's can provide voice, data, and more. [Ananasso, 1995]

Among the big LEO's, I will briefly talk about some of the programs I consider to be the most representative: Iridium, Globalstar and Teledesic. However, there are other similar programs under development. ORBCOMM is the leader among small LEO's. I will devote the next chapter to a description of ORBCOMM.

B. LOW EARTH ORBIT SATELLITES

In Low Earth Orbit (LEO), the satellite's altitude is lower than 6000 Km. (a period of less than 225 minutes). Usually, LEO satellites are placed at altitudes between 500 Km and 2000 Km. If the altitude is lower (with a period less than 95 minutes), the upper atmosphere produces considerable drag, making it difficult to maintain orbit. If the altitude is higher than 2000 Km, radiation from the Van Allen Belt affects the electronics. Also, the higher the orbit, the higher the cost to achieve it. However, a higher orbit expands the ground coverage area.

While a GEO satellite is continuosly in view of the earth station, a ground station can only view a LEO satellite for about 10 to 20 minutes per orbit. To assure continuous coverage, a constellation of satellites is required such that when one satellite is setting over the earth station horizon another is rising. Table 4.1 provides some parameters of low Earth orbits which form the basis for building a constellation. Altitude is measured from the surface of the earth, and the orbit is considered circular, so the radii of apogee and perigee are the same. Note that when altitude increases, the period increases, and the number of revolutions per day decreases. The time in view increases with altitude, as does

the maximum range (radius of the area covered with respect to the nadir point on the Earth).

Table 4.1. Parameters to consider for a LEO satellite constellation. [Larson and Wertz, 1995]

Altitude (Km)	Orbital Period (Min)	Revolutions Per Day	Max. time in view for elevation 5° (min)	Max. range for Elevation 5° (Km)	Max. Earth Central Angle for elevation 5° (degrees)
500	94.62	15.22	9.21	2078	17.52
550	95.65	15.05	9.83	2206	18.49
600	96.69	14.89	10.43	2329	19.42
650	97.73	14.73	11.02	2448	20.3
700	98.77	14.58	11.6	2563	21.15
750	99.82	14.43	12.17	2675	21.95
800	100.87	14.28	12.74	2784	22.73
850	101.93	14.13	13.29	2890	23.47
900	102.99	13.98	13.84	2994	24.19
950	104.05	13.84	14.38	3095	24.88
1000	105.12	13.7	14.92	3194	25.55
1250	110.51	13.03	17.56	3665	28.6
1500	115.98	12.42	20.13	4102	31.24
1750	127.2	11.32	25.21	4905	35.68
2000	138.75	10.38	30.3	5645	39.3

To set up a simple example, consider a constellation formed by satellites located in circumpolar orbits at an altitude of 1000 Km.[1] One satellite will make about 13.7 revolutions per day (Table 4.1). The plane of the orbit will be inertially fixed in space but moving with respect to the Earth. The Earth revolves 360 degrees per day, and the satellite completes 13.7 revolutions per day, so when the satellite has completed one period, the Earth has revolved 26.27 ° (360°/day divided by 13.7 revolutions/day = 26.27°

[1] Circumpolar orbit is an orbit with 90 degrees of inclination. The plane containing a circumpolar orbit is perpendicular to the plane of a geostationary orbit.

of Earth rotation per orbit completed by a satellite). For the chosen altitude, the maximum Earth Central Angle λ_{max} (Figure 3.1) is 25.55 degrees for 5° of elevation. Remember that Swath Width= 2 λ_{max} [Chapter III], so for this case the swath width will be 51.1 ° for 5° of elevation. If we wanted continuous coverage at the Equator, we would need the number of satellites resulting from dividing 360 ° by the swath width of each satellite, so 360°/51.1°/satellite = 7.04 satellites. If we can distribute the appropriate number of satellites in each orbital plane, we can have one satellite on view at the equator in one side and other in the opposite side, so each orbital plane will be able to provide two satellites on view simultaneously and continuously. To avoid more complications, I assume we would like to have some overlapping, so we need eight satellites on view at the equator each time. Four orbital planes can provide that. The time in view is about 12.64 minutes for each satellite with respect to any ground station, so if the period is about 105 minutes, we will need 105 minutes/12.64 minutes/satellite on view = 8.3 satellites on view (8 or 9 depending on how we adjust other technical factors). In conclusion, in order to have continuous global coverage using this configuration and these assumptions, we will need a constellation composed of nine satellites in each of four orbital planes. Note that near the poles, individual satellite coverage will overlap unnecessarily. One of the points to consider is what kind of coverage is required. For example, changing the inclination makes it possible to maximize coverage at lower latitudes where the population and demand is concentrated, rather than near the poles, where the population density is low.

C. WHAT CIVILIAN SPACE COMMUNICATION BIG LEO'S SYSTEMS COULD BE AVAILABLE FOR ARGENTINE IN THE FUTURE?

1. IRIDIUM

a. Background

Between 1987 and 1990, Motorola developed a new satellite system to provide continuous telephone service around the globe. The original concept was to establish a LEO satellite constellation of seventy-seven satellites ("Iridium" was chosen because the atomic number of Iridium is seventy-seven). Later, the constellation was modified to include only sixty-six satellites, but the system name remained the same. In January 1995, the FCC granted the Iridium system license for construction and operation in the U.S. Intended to provide a wireless personal communications network, the system will cover a wide range of services like voice, data, facsimile and paging with worldwide coverage. One of the important characteristics is that the Iridium system uses L-Band frequencies with Time Division Multiple Access (TDMA) and Frequency Division Multiple Access (FDMA), and the terminals will allow the user to connect to it using the local existing cellular telephone network. [Maine, 1995]

b. System architecture

The system is composed of a space segment, a ground segment and subscriber terminals.

(1) Space Segment. The space segment is comprised of sixty-six LEO satellites positioned in six near-polar orbital planes with eleven satellites each plane. Satellites in the first and last plane are counter-rotating. The separation between these

two planes is 22°, and the rest are each separated by 31.6 °. Figure 4.1 Illustrates the constellation.

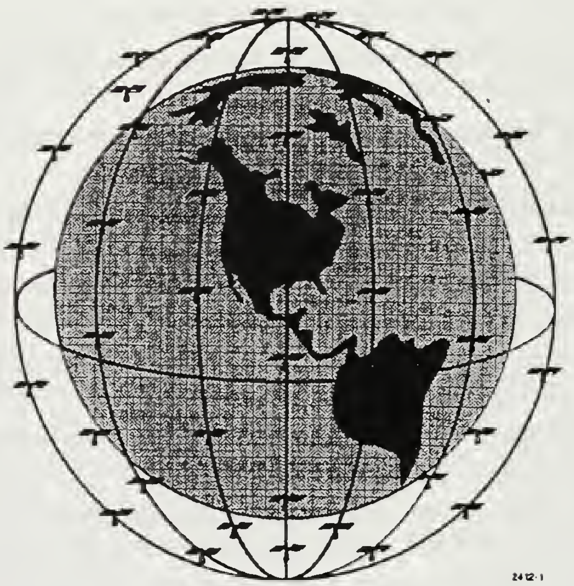

Figure 4.1. IRIDIUM Satellite Constellation

Many constraints were considered to decide on the position of the satellites, the primary being continuous coverage of the entire Earth. The time delay that the signal must experience traveling through the atmosphere and space was another. Satellites located in GEO generate delays of more than 250 ms which is considered unsatisfactory for real time voice communication. Low altitude space flight creates undesirable drag, so the chosen altitude was 787 Km apogee and 768 Km perigee, and the inclination was 86.4° [Leopold, 1993]. The satellite itself is triangular in shape, and weighs about 700 kg, with a length of about 2 meters. (Figure 4.2)

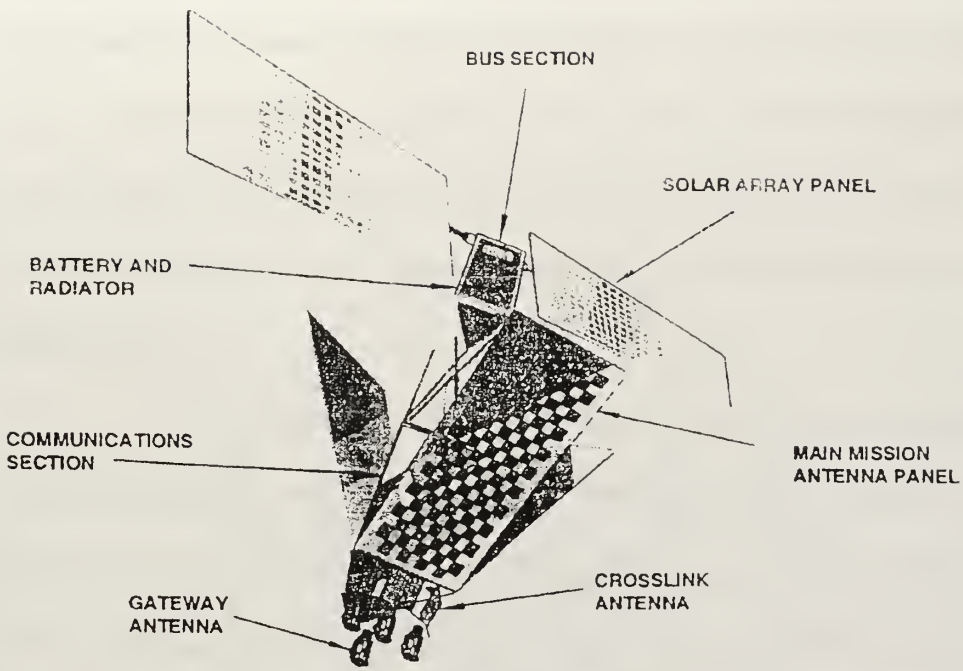

Figure 4.2. Iridium Satellite.

The satellite is the dominant element of the system architecture. Iridium is the only currently proposed big LEO system that provides inter-satellite communications cross-links, so it must perform more tasks on board. Each satellite has four cross-link antennas oriented to the four nearest satellites: forward and aft in the same orbital plane and in the two adjacent co-rotating planes. Feeder link antennas are used to relay information to the system control segment and the terrestrial gateways. To assure the appropriate coverage for the subscribers, 48 beams are provided by three L-Band antenna panels. As the satellite beam footprint moves over the ground, the subscriber signal is switched from one beam to the next or from one satellite to the next. This footprint is shown in Figure 4.3. The big circle represents the satellite beam formed by the 48 beams The satellite

was developed by Motorola SATCOM and is going to be produced on a large scale. The company says it is using a continuous improvement process to achieve high quality. [Maine, 1995]

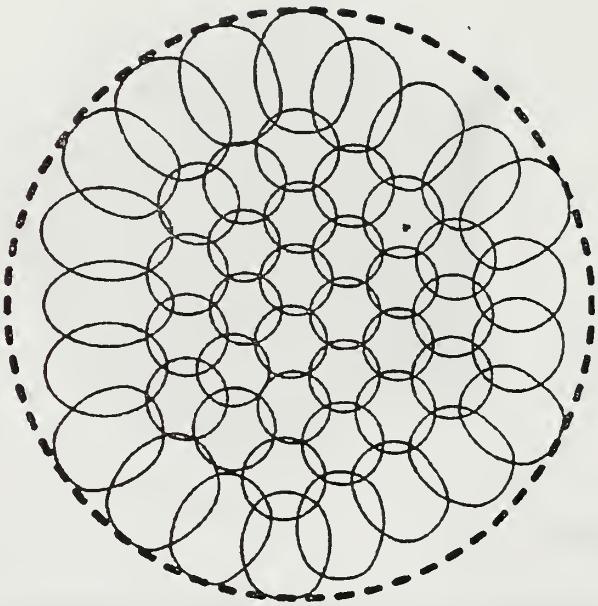

Figure 4.3. Satellite footprint coverage

(2) Ground Segment.

(a) System Control Segment (SCS). The SCS is responsible for tracking, telemetry, and attitude control information; monitoring electrical and power systems; and managing the communications network by sending the appropriate information to re-route calls when some node is out of service.

(b) Gateways. The purpose of a Gateway is to connect the satellites to the Public Switched Telephone Network (PSTN) and

collect the appropriate information for billing. Access to the system is controlled geographically, so if some local regulation prohibits its use, it will not be possible to use it. Each gateway will use at least three 3.3 meter antennas, separated by at least 20 miles to avoid the negative effects of a thunderstorm. It is expected that the system will have more than 10 gateways around the world when fully implemented.

(3) Subscriber Units. Motorola will offer variety of subscriber units: hand held portable units, mobile units that can be installed in cars or boats, transportable units that can be moved from fixed points and paging products. Figure 4.4 shows the Motorola hand-held Subscriber Unit, intended to be compatible with terrestrial cellular phone networks as well as the satellite system ("dual mode telephone"). The battery system will allow 24 hours of stand by operation on a single charge (talk time will reduce this). [Leopold, 1993]

Figure 4.4. IRIDIUM Hand-Held Subscriber Unit.

c. Capabilities

The IRIDIUM configuration provides:

-Voice capability using dual mode telephones with high quality transmission, reduced time delays, and world-wide coverage. Access to the system is based on TDMA and FDMA to maximize the use of the frequency spectrum. The digitized voice is transmitted at a rate of 4800 bps. The phone terminal requires low power and a low profile antenna.

-Paging capability, compatible with most of the existing paging devices.

-FAX capability, through the subscriber units, with a data rate of 2400 bps. Subscriber units will have a built-in data port for interface with an external facsimile machine. [Maine, 1995]

2. GLOBALSTAR

a. Background

GLOBALSTAR combines satellites and existing cellular systems to provide personal communication services (PCS) to areas in which traditional telephone systems are not economical. Each subscriber will have a unique number that he or she can be reached at wherever he or she is (in the office, in the car, at sea, at home or in rural areas). A small, inexpensive communicator allows the subscriber to be connected for services like voice, data, facsimile, message and position location

To provide low-cost, pocket-size communicators, existing technologies must be used. GLOBALSTAR adopted Code Division Multiple Access (CDMA), which is cost effective and frequency spectrum efficient.

The system will be built by Loral and Qualcom, Loral being an experienced spacecraft manufacturer and Qualcom being an active cellular mobile radio supplier. It is expected that this combination will be beneficial for the entire program. [Louie, 1994]

b. System Architecture

(1) Space Segment.

(a) Constellation. The constellation will consist of forty-eight satellites distributed in eight orbital planes (Figure 4.5).

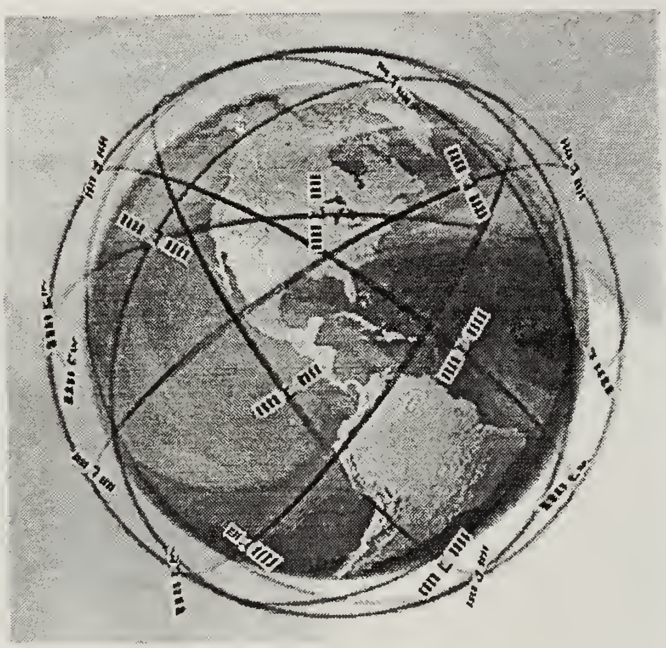

Figure 4.5. GLOBALSTAR Satellite Constellation

The altitude will be 1370 Km and the inclination 52°. The satellites will provide coverage up to 71.5 ° of latitude north and south, so the polar areas will remain uncovered. The separation between planes will be 45 °, and each plane will have six satellites equidistantly distributed. The corresponding period for the satellites is 114 minutes. The program will be developed in two phases. During the first phase, twenty-four satellites will be put into orbit and will provide continuous coverage of the U.S. The second phase will complete the constellation and will provide services for the rest of the world.

(b) Satellite. The satellite appears to have the simplest spacecraft design compared to the other LEO systems offering similar capabilities. It is composed of a single bent-pipe repeater and a simple antenna system that generates 16 beams. The weight is about 450 Kg and the expected life is 7.5 years. The body of the satellite (Figure 4.6) is trapezoidal in shape and stabilized by three-axis attitude control. It has C-Band antennas for communications with the gateway and L-band and S-Band antennas for communications with user terminals. [Johansen, 1996]

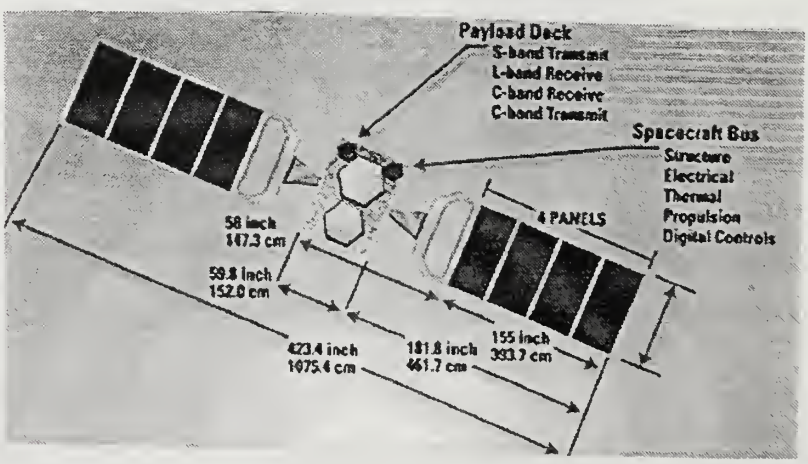

Figure 4.6. GLOBALSTAR Satellite

(2)Ground Segment

(a) Gateways. The main function of the gateway is to handle the interface between the GLOBALSTAR Network and the Public Switched Telephony Network (PSTN). Each gateway will communicate with three satellites simultaneously and will be able to determine the position of the user terminal to an accuracy of 100 to 300 meters without an additional GPS receiver in the terminal handset.

(b) Network Control Center. The NCC is responsible for managing GLOBALSTAR services: billing, channel allocation, registration, verification and message services. Initially, one NCC will handle cellular systems in the US, and there will be other NCC's distributed world wide as the system expands.

(3) User Terminals. There will be three classes of GLOBALSTAR terminals. Hand-held terminals will be pocket-size, and easily transportable. They could be connected to either the terrestrial cellular phone network or satellite network, and they will provide the geographic location of the user. Mobile terminals will have the same capabilities as hand-held terminals but would be a little larger and could be installed in cars or trucks. Finally, fixed terminals will only operate with GLOBALSTAR system.

c. Capability and Frequencies

The coverage excludes the high latitudes, but in the most populated areas, there will be more than one satellite available. The system works using Code Division Multiple Access (CDMA), which allows the user to carry the same personal communicator anywhere. All communications will be processed on the ground by the gateway station, so it will not have inter-satellite links. That means that in the middle of

the ocean, although satellites may be in view of the user terminal, it will not be possible to communicate if the nearest gateway is out of range of those satellites.

The frequency plan is:

Terminal to satellite: L-Band (1610- 1626.5 Mhz)

Satellite to terminal: S-Band (2483.5-2500 Mhz)

Gateway to satellite: C-Band (5091-5250 Mhz)

Satellite to gateway: C-Band (6875-7055 Mhz)

Although the WARC-92 had allocated the 1885-2025 Mhz and 2110- 2200 Mhz bands for world-wide use in Future Public Land Mobile Telecommunications Systems (FPLMTS), it specified that this allocation will start in the year 2005 outside the U.S. The U.S. is already using the 2 Ghz frequencies proposed for PCS, so the rule approved by the FCC is that the licensed PCS operators will have to negotiate with the incumbent users and compensate them when they move to other bands. [Louie, 1994]

Each single beam will support up to 2000 channels without interference, but the satellite power limits raise this number to 2400 channels of 1.25 Mhz. The bit rate varies from 2400 bps to 9600 bps, and the voice is digitized and encoded to provide high quality.

3. **TELEDESIC** [Sturza, 1994] [TELEDESIC Corporation, 1997]

a. Background

At the end of another edition of the World Administrative Radio Conference (WARC-95), Teledesic corporation promised that a $9 billion dollar LEO satellite communication system would be operating by 2001. The most important

achievment for Teledesic was that 400 Mhz bandwidth in the 19 and 29 Mhz bands would be available immediately. Led by Microsoft Chairman Bill Gates and McCaw Cellular founder Craig McCaug, Teledesic promised to provide a global Asynchronous Transfer Mode service using a network of 840 active LEO satellites. The goal was to build a satellite based internet capable of providing the internet service we have today in the U.S. and developed countries worldwide, at a reasonable cost.

The objective of providing inexpensive broad-band transmissions for multimedia and other applications convinced the WARC-95 to allocate a piece of bandwidth to Teledesic before the company began raising the necessary $9 billion. In short, Teledesic promises an overwhelming number of satellites with high quality voice, data, videoconferencing and interactive multimedia.

b. System Architecture

(1) Space Segment.

(a) Constellation. The constellation will have 840 active satellites distributed in twenty-one orbital planes inclined 98.2°, along with 84 spare satellites (up to four in each orbital plane). The separation between orbital planes at the point of ascending node will be 9.5 °, and the satellite altitude varies between 695 Km and 705 Km. The low altitude was chosen to minimize the end-to-end time delay and to assure a reliable communications link using low power and small antennas. This is combined with a required high elevation angle of the antenna (the antenna needs to see the satellite with more than 40 ° elevation with respect to the horizon) resulting in small area coverage per satellite and a higher number of satellites required.

(b) Satellite. This quantity of satellites requires the ability to be launched by many different vehicles. Teledesic satellites are compatible with more than 20 different launch vehicles, and several satellites can be launched together. In orbit, the satellite looks like a flower with eight petals and a large boom- mounted square solar array (Figure 4.7). When deployed, the satellite is 12 meters in diameter and the solar array is 12 meter on each side. The heart of the payload is the Fast Packet Switch (FPS) responsible for routing packets of data to and from the scanning beam (SB), Gateway Satellite link (GSL) and Inter-Satellite Link (ISL) transmitters and receivers. It also has a computer system that provides information control. Eight pairs of antennas support the Inter-satellite Link with eight other satellites. Each satellite contains a three bus structure, two of which provide engineering subsystem components and thrusters, and a third which provides power equipment and additional thrusters.

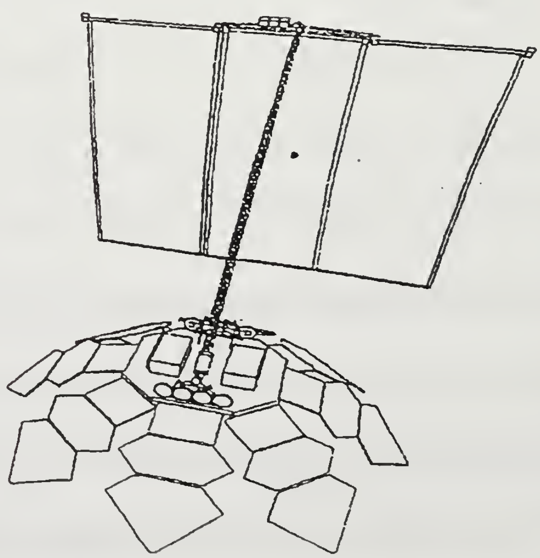

Figure 4.7. TELEDESIC Satellite

(2) Ground Segment. The ground segment will be composed of GigaLink terminals, Network Operations and Control Centers (NOCCs) and Constellation Operation and Control Centers(COCCs).

(a) GigaLink terminals. They will provide gateway connection from the satellite to internet and to Teledesic support and data base systems, including NOCCs and COCCs, as well as to privately owned networks. Each satellite will be able to support up to sixteen GigaLink terminals within its service area. Each GigaLink terminal will operate at the rate of 155.52 Mbps and multiples of this rate up to 1.244 Gbps. The required antenna for this terminal will be about 28 cm to 1.6 meters in diameter, and the required transmit power from 1 to 49 watts.

(b) Network Operations and Control Center. Comprised of database systems, the NOCC's will be responsible for network administration and control, billing, troubleshooting, call routing data, authentication and encryption keys.

(c) Constellation Operations Control Centers. Designed to operate with a high degree of autonomy, it will be responsible for monitoring satellite health and uplinking maintenance commands. The initial constellation will include a number of spares, but periodical launches will be scheduled to replace the satellites that go out of service.

(3) Users Terminal. Standard terminals will be of stationary and transportable configurations, operating at multiples of 16 Kbps up to 2.048 Mbps (128 channels of 16 Kbps). The antennas would be from 16 cm to 1.8 meters in diameter and

the required power from .01 Watts to 4.7 Watts. All of the communication links will transport data and voice at a fixed length of 512 bit packets.

c. Capability

The Teledesic system plans to offer capabilities found today only in advanced terrestrial networks. Voice, data and video based in Asynchronous Transfer Mode (ATM) technology.[2] The company says that it will market these services at reasonable prices, although we don't know exactly what "reasonable" means. As main features, we can mention:

- Ka band frequency, uplink 30 Ghz, downlink 20 Ghz.

- Capable of providing services to 20 million subscriber terminals with a peak load of more than 2 million.

-95% of earth surface coverage and 100% of the population. Up to 72° north or south latitude, twenty-four hours a day. In the higher latitudes (more than 72°) the coverage is available but only at certain times of the day.

-Supported by the 16 Kbps basic channel, which may enable the system to meet "network quality standards" [Sturza, 1994]. The bit error rate (BER) expected is less than 10^{-9}.

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[2] ATM technology is designed to provide high bandwidth. A typical connection between a computer and an ATM switch operates at speed of 100 Mbps or faster. The connection between a computer and an ATM switch is supported by a pair of optical fibers [Comer, 1996].

- Capable of supporting from 16 Kbps to T-1 (1.544 Mbps), E-1 (2.048 Mbps), OC-3 (155.52 Mbps) and OC-24 (1.24416 Gbps) standards, which means that the system can support many different users.[3]

4. Probable Availability

It is difficult to determine exactly how many of the systems just described we will be able to use in Argentina. Most of them are advertised as providing global coverage, but at the moment, there are barriers to starting operations either locally or internationally. Protective legislation or the demand of tax payments to operate them can raise the cost and make them less attractive than existing systems.

Although Iridium and GLOBALSTAR expect to start offering services in 1998, we do not know how long we will need to wait to be able to use them. As I mention before, the frequency allocation established by the WARC-92 will not begin until January 2005. Most of the systems promise full coverage for the U.S. from the beginning, which implies that the rest of the world may need to wait.

The systems work through the ground stations, so the cost will most likely depend on the number of customers, and the companies will probably concentrate their efforts in places were the demand is higher, like Southeast Asia and Europe Using the Teledesic case as an example, the program is still unfunded and is showing the first delays, originally promising services for the year 2001, but now talking about 2002 Considering what

[3] T-1, E-1, OC-3, and OC-24 are different types of wire used in networks, differentiated basically by their bandwidth capability.

happened with other commercial projects and the magnitude of the Teledisc program,[4] I do not think that we can expect to have any service before the year 2005. The starting point for the other systems is also uncertain.

D. MILITARY APPLICATIONS

As I mentioned in Chapter III, the need for satellite communications is driven by the need to improve our C^3I/C^4I capabilities. The U.S. Navy is looking for ways to increase data transmission capability. If they can relieve some military satellites of being used for administrative traffic, they will be able to use them more effectively for operational traffic.

The incorporation of satellite communications into the Argentine C^3I architecture means the addition of more capabilities. How well this capability would be used with tactical or administrative purposes is something that needs to be experienced on the battlefield taking into account the limitations and condition of our theater of operations. A good example was the use of commercial portable GPS equipment by the Coalition Forces during the Persian Gulf War. Warfighters from all branches of the service solved their location problem, a big problem in a desert, using commercial GPS receivers.

The Coallition Forces answered the question of whether or not commercial communications systems can be used for military purposes in the Gulf War by increasing the number of INMARSAT stations installed on board warships during that year.

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[4] For example, the ORBCOMM project, clearly less ambitious than Teledesic, promised to have twenty - six satellites operating by 1995, but only the first two for testing have been launched.

1. Benefits

a. No system development required

The system will be commercially available, so the main requirement will be the subscription to the service, the acceptance of the fee, and the user terminal acquisition. However, we can not forget that training, testing and operating protocol development must be achieved as in any other system.

b. No special installation required

Most of the commercial satellite communication systems are designed to provide services to the end user, basically oriented toward hand-held terminals or lap-top computers. The only system in which some particular new technology will be probably necessary is Teledesic. Asynchronous Transfer Mode (ATM) technology is not sufficiently standardized, but at the speed with which computers and communications are advancing, we can expect that the equipment that uses it will soon be available.

c. Mobility

The user terminals offered are easily transportable, with low power requirements, so they can provide useful communications for troops in transit. If we use Teledesic, we should expect to be able to connect a lap-top computer to the terminal and receive high data rate data and video anywhere.

d. Public Switch Telephone Network Compatible

Like INMARSAT, most of the services I mentioned can provide communications between units deployed in remote areas and their original commands through the PSTN.

e. Low Cost

The estimated costs in the U.S. are about $750 for a Globalstar Terminal and $2000 to $3000 for an Iridium terminal. The monthly fee could be similar to a normal cellular telephone fee. In the U.S., a monthly subscription to Globalstar would cost about $8 to $ 10 plus $0.30 per minute plus $ 0.10 for connecting long distance calls. Motorola expects to charge $3 a minute. Teledesic expects to charge a fee comparable to that for similar services provided by terrestrial networks. [Haralambos, 1996]

f. Coverage

The Iridium system will provide global coverage, so it could be used near the poles, which would include Antarctic bases. GLOBALSTAR will cover up to 74° latitude North and South and Teledesic up to 72 ° latitude North and South. Note that only Iridium will avoid the coverage limitation that currently exists with INMARSAT.

g. Timely availability

It is expected that the link could be established when required so users would experience a very small delay under normal circumstances

h. Flexibility

A combination of these systems can provide the flexibility required for military operations. This will require particular rules and alternative communication plans.

2. Disadvantages

a. Reliability

All of the proposed systems will be operated by foreign (non-Argentine) companies. Although Argentina can own a ground station and partially control the service, the ultimate control will be outside of our country.

GLOBALSTAR, which was designed to use CDMA, offers some protection against jamming, but the other systems can be very vulnerable to hostile jamming. The point favoring the reliability is the number of satellites. If something happens to one satellite, the entire system will still operate. One important consideration is that the entire system is built to serve a large number of worldwide users, and any action against the system could affect more than the hostile user. This action could generate more international problems than temporary local benefits.

b. Security

Commercial systems are designed to provide some kind of security to prevent an intruder from using someone's account. Also, commercial companies require protection for their message content, so some form of commercial encryption should be

available. However, the best encryption systems are still vulnerable to a technologically sophisticated listener.

c. Interoperability

Because different system developers will be using different voice coding algorithms, and there are no standards yet defined, one type of terminal (say, Teledesic) may not be able to communicate directly with other type (say, Globalstar).

d. Priority

Access to the systems will be based in general on the three known modes, TDM, FDM and CDM. The system will be shared with commercial users, so it is possible that in crowded areas at particular times military communications may be delayed awaiting the corresponding slot, unless some priority was established. This will, of course, increase the cost of the service. Nevertheless, the expected delays should not be of considerable magnitude.

E. SUMMARY

Argentine military forces, and the Navy in particular, could use Low Earth Orbit satellites in the future. Exactly when the systems will be available to our country is not yet defined. However, once the satellites are in orbit, the companies will try to sell their products to the greatest number of clients. What should our policy be with respect to these products? First we need to recognize that although they have tactical limitations, the systems promise services that can increase our communications capacity considerably.

I believe that we should use leased systems to start learning how to improve our capabilities based on tangible needs and limitations.

V. ORBITAL COMMUNICATIONS CORPORATION (ORBCOMM) DIGITAL DATA COMMUNICATION AND POSITION SYSTEM

A. INTRODUCTION

The ORBCOMM digital data communication and position determination system was conceived as a commercial system with world-wide coverage, able to provide only data and message communications, similar to alphanumeric paging and electronic mail, at a low data rate (2400-4800 bps). It also has many military applications. The ORBCOMM system will use a constellation of twenty-six to thirty-six small spacecraft in Low-Earth Orbit (LEO) combined with the appropriate terrestrial stations and small, inexpensive user terminals.

The system is based on a "store and forward" principle, but is designed in such a way that it can provide near real time message transfer over the most crowded latitudes.

The ORBCOMM user will be able to transmit and receive messages, control and monitor distant equipment, and collect data using hand-held Subscriber Communicators (SC's). The user can send a query from an operational center or with their own personal SC to check the status of an asset or to program the asset to send data about a specific event. A message transmitted from an SC and received by the satellite is relayed down to a regional Gateway Earth Station (GES), then directed to the Network Control Center (NCC) using land-lines or Very Small Aperture Terminals (VSAT).[1] The NCC determines the validity of the message and location of the recipient, then routes the message back to

[1] Very Small Aperture Terminal (VSAT) is a type of inexpensive earth station that takes advantage of new digital technology and can reduce the physical dimensions and power of the ground station.

the GES and relays it through the satellite, which sends it down to the SC's receiver. The NCC can also receive and transmit messages from terrestrial networks through X.400 and X.25 gateways. The NCC is designed to translate messages from widely used electronic mail systems, such as Microsoft Mail, into X.400 messages for transmission to and from ORBCOMM SC's [Reut, 1995].

I chose ORBCOMM as an example, because it is the first in its class, the most advanced, and, although I believe it has considerable limitations, its services will probably be offered to the Argentine Navy in the future.

B. BACKGROUND

In February 1990, Orbital Communications Corporation (ORBCOMM), a subsidiary of Orbital Sciences Corporation (OSC), applied to the United States Federal Communications Commission (FCC) for permission to create a new LEO satellite system for mobile communications. In March 1992, the FCC granted ORBCOMM an experimental license to operate two satellites and up to 1,000 user terminals (Subscriber Terminals)[Aguerrevere, 1996].

In January 1993, the FCC allocated the frequencies of 137-138 Mhz down link and 148 - 150.05 Mhz up link for ORBCOMM mobile satellite services.

In 1993, an international alliance made between Orbital Science and Teleglobe (Canada), one of the biggest telecommunications company on the world, provided all funding for the project. In 1994, ORBCOMM received the final approval for the construction and operation of the constellation, composed of its thirty-six communication satellites. The ITU licensed GE Starsys, ORBCOMM's competitor, in 1995 [Hara, 1994].

ORBCOMM designed its system with the primary objective of finding the configuration that represented the lowest-cost service to users, rather than finding the best technical solution. To make this possible, engineers were forced to look at unusual approaches to solving traditional design problems. They decided to create a system which operates in the VHF frequency band, because (among the other reasons) in this range of frequencies, it is easy to find appropriate proven technology [Hardman, 1991].

On April 3, 1995, ORBCOMM launched the first two satellites and operated them successfully by sending thousand of messages to subscriber terminals throughout the United States. ORBCOMM launched its commercial operations on February 1, 1996, but restricted use to the existing two satellites and ground stations.

Originally, the ORBCOMM constellation was supposed to have thirty-six satellites, established in six different orbital planes, four of them inclined 45 degrees and the other two planes inclined 70 degrees to assure polar coverage. By 1996, the company goal had changed to have twenty-six satellites in orbit by 1997: the two original satellites plus twenty-four launched in three different Pegasus vehicles during the year. Although the OSC launch vehicle, Pegasus, had problems during 1996 (for example, the failure during the launch of the Argentine SAC-B), the company believes that these problems will not affect the ORBCOMM launch schedule [Reut, 1996].

ORBCOMM is actually building thirty-two satellites with the idea of putting a total of twenty-six into orbit. The other eight will serve as backups in case of a launch failure or if the increase in demand justifies it. They would meet increasing demand by establishing a new orbital plane, which would increase the capacity of the system.

As a confirmation that there is still a market for small LEO's, Final Analysis Inc. (Lanham, Md.) is planning to launch a constellation of twenty-six satellites and offer the same services as ORBCOMM and GE Starsys [McCaffery, 1997].

C. SYSTEM ARCHITECTURE

The ORBCOMM system is composed of a space segment, a ground segment and user terminals. The appropriate distribution of these three elements should allow the end user to communicate quickly and reliably between locations anywhere in the world, including the polar regions.

1. Space Segment

a. Constellation

The constellation will consist of twenty-six satellites in circular orbits with an altitude of 775 km. The first two satellites, already launched, tested, and in service since 1996, are deployed in near-polar orbits with an inclination of 70 degrees. The remaining twenty-four are expected to be launched in 1997 in three different groups using the Pegasus Launch Vehicle. Each group will be deployed in an orbital plane inclined 45 degrees and spaced 135 degrees apart at the point of the ascending nodes. The period for this altitude is about 100 minutes, and the maximum range at 5 degrees elevation is about 2730 Km. So, at any instant, a satellite is covering a circular area about 5460 Km in diameter (Table 4.1). The conjunction of these characteristics determine that each satellite can be used for about 12 minutes in each passage above the local zenith.

The constellation arrangement is the key to the problem of providing the maximum world-wide coverage and availability. Figure 5.1 shows the instantaneous coverage for a fully deployed constellation of thirty-six satellites. In this case, it could take up to two minutes to acquire a satellite at medium latitudes.

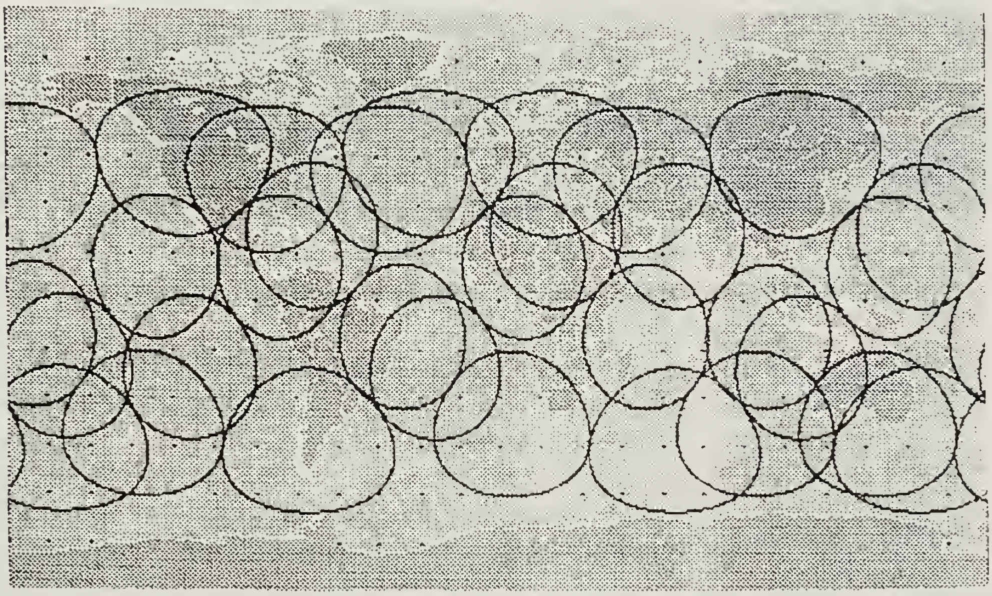

Figure 5.1. ORBCOMM instantaneous coverage for a constellation of 36 satellites [Hara, 1994].

Figure 5.2 shows the instantaneous coverage when the constellation is formed by only twenty-six satellites. In this case, it could take up to ten minutes to acquire a satellite at medium latitudes.

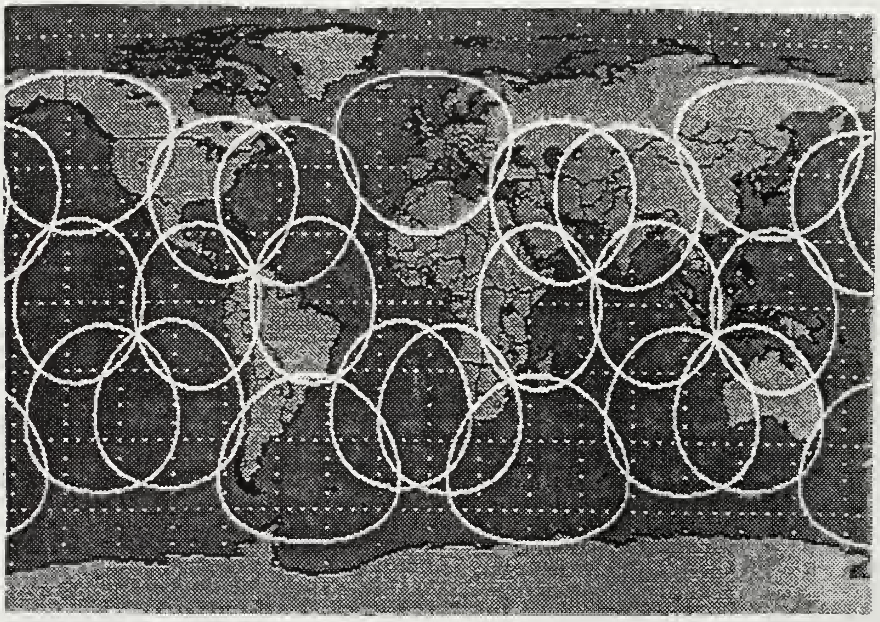

Figure 5.2. ORBCOMM instantaneous coverage for a constellation of 24 satellites [Burgess, 1996].

b. Satellite

An ORBCOMM satellite weighs only 95 pounds. For a comparison of satellite size, the spread spectrum communications satellite built at the Naval Postgraduate School, PANSAT, weighs 150 pounds. The ORBCOMM satellite's small size, relative to other commercial communication satellites, is a result of clear design objectives and the minimization of launch and development costs while maximizing coverage. The engineers maintained this goal throughout the entire design process. In general, the cost of putting a satellite into orbit is directly proportional to its weight, hence the lower the weight, the lower the launch cost. Figure 5.3 shows the satellite configuration.

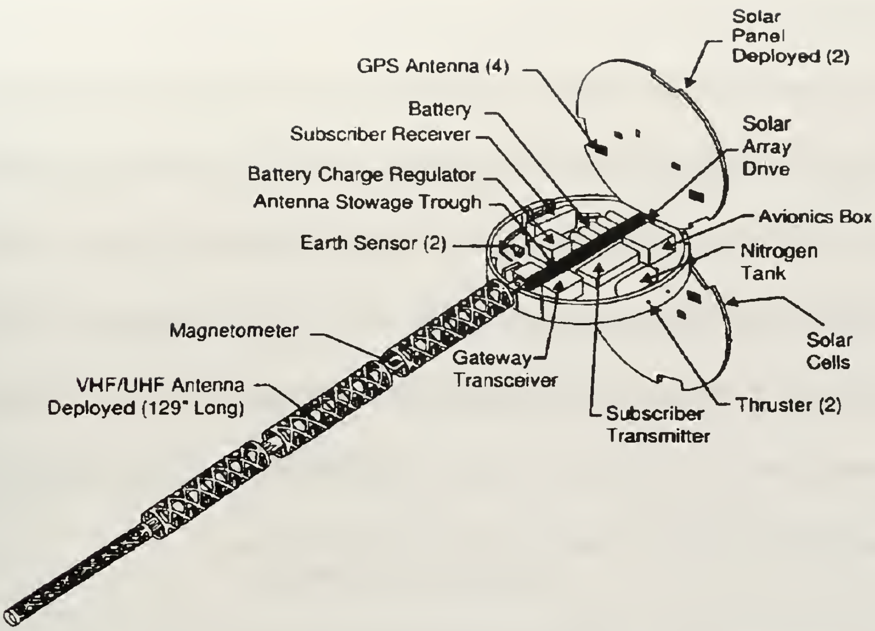

Figure 5.3 ORBCOMM Satellite Configuration [Burgess, 1996].

One of the prevailing constraints engineers faced during design process was the need to launch eight satellites together in one Pegasus launch vehicle, which limited the possibility of redundant systems in the satellite. Although seven satellites could have been enough for each orbital plane, the eighth satellite was added to provide enough reliability in the event that one satellite in the plane fails. Another important concept used by ORBCOMM was to only build what they could not buy. This reduced development time and cost. To ensure that the chosen components would survive the space environment, OSC increased the amount of testing on parts that could be affected by radiation, which is the most significant cause of degradation of electronic components in the space [Burgess, 1996].

2. Ground Segment

The Ground Segment is comprised of Network Control Center (NCC), Satellite Control Center (SCC) and Gateway Earth Station (GES). This segment contains most of the system intelligence (the brain). On larger, more expensive systems, much of this would be on the satellite. The advantage of keeping most of the intelligence on the ground is that it allows the satellite be smaller, but the disadvantage is that each message must be directed through both the GES and NCC. The satellite is unable to direct a message by itself, even if it has both the sender and the receiver in view.

a. Network Control Center (NCC)

The Network Control Center provides message routing and customer services, which includes customer monitoring and billing. It is owned and operated by ORBCOMM in the U.S. and by each licensee abroad. The NCC will route the messages according to their addresses using Transmission Control Protocol and Internet Protocol (TCP/IP)[Comer, 1997]. The NCC is connected to the GES by leased lines, the public data network, or Very Small Aperture Terminals (VSAT). A country having a license to operate the ORBCOMM system may have an NCC and as many GES's as necessary to provide entire coverage in near real time. For example, in the US, one NCC and four GES's are enough.

b. Satellite Control Center

The Satellite Control Center (SCC) is located near the main NCC in Dulles, Virginia, US. It is the only place from which the satellites can be commanded and the

telemetry of the satellite subsystems monitored. As the satellites come into view of the U.S. GES, the system initiates an automated "State-of-Health" check. If no problems are detected, the system will store the telemetry data. If problems or malfunctions are found, the SCC operator will take the necessary corrective actions to get it back to normal operation. Telemetry from other NCC's could be received and relayed to the U.S. NCC, but ORBCOMM does not anticipate solving major problems when the satellite is not in view of the U.S. SCC [Yarbrough, 1995].

c. Gateway Earth Station

The Gateway Earth Station (GES) provides the link between the ground segment and the space segment. The GES's are unattended, and they communicate with the visible satellite just uplinking or downlinking the messages in accordance with the orders received through the NCC. Through these orders, the NCC indicates which satellite should be tracked by the GES. The basic functions of the GES are:

-Acquire and track satellites based on orbital parameters received from the NCC

-Transmit to and receive messages from the satellites

-Transmit to and receive messages from the NCC

-Monitor status of local GES hardware and software

-Monitor the system level performance of the satellite linked to the NCC.

Each GES has two steerable high-gain VHF antennas that track satellites as they cross the sky. The GES transmits to the satellite 56.7 Kbps in the 148.0-150.05 MHz range at 500 watts. The GES receives a 3 watt transmission from the satellite in the

137.0-138.0 Mhz band [Reut, 1995]. Figure 5.4 provides an overview of the ground segment configuration.

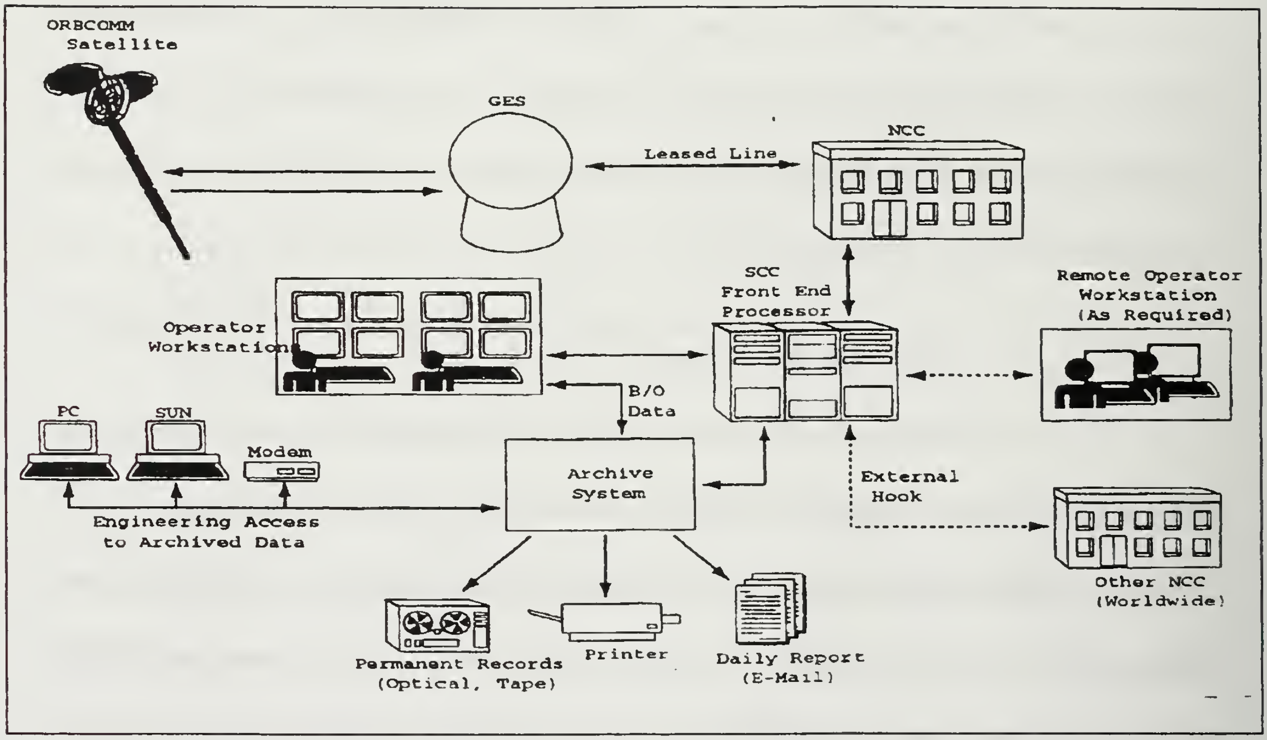

Figure 5.4. ORBCOMM Ground System Configuration [Yarbrough, 1995].

3. Subscriber Terminal (Users Terminal)

The Subscriber Terminal, also called the Subscriber Communicator (SC), is the piece of hardware used by customer to establish communications with the ORBCOMM system. There are a variety of SC models being developed by different manufacturers (Panasonic, Tadiran/Elisra, Magellan and Torrey Science) which all have agreements with ORBCOMM. According to these agreements, the manufacturers produce the hardware

and ORBCOMM provides the appropriate software to allow communication with the satellites.

The SC is composed of an antenna, computer interface and power source. Some of these SC units are only data communicators that function like a modem, so someone is able to connect his or her personal computer to the SC and start his or her communication. Others include keypads and integral GPS receivers. Figure 5.5 shows different SC types.

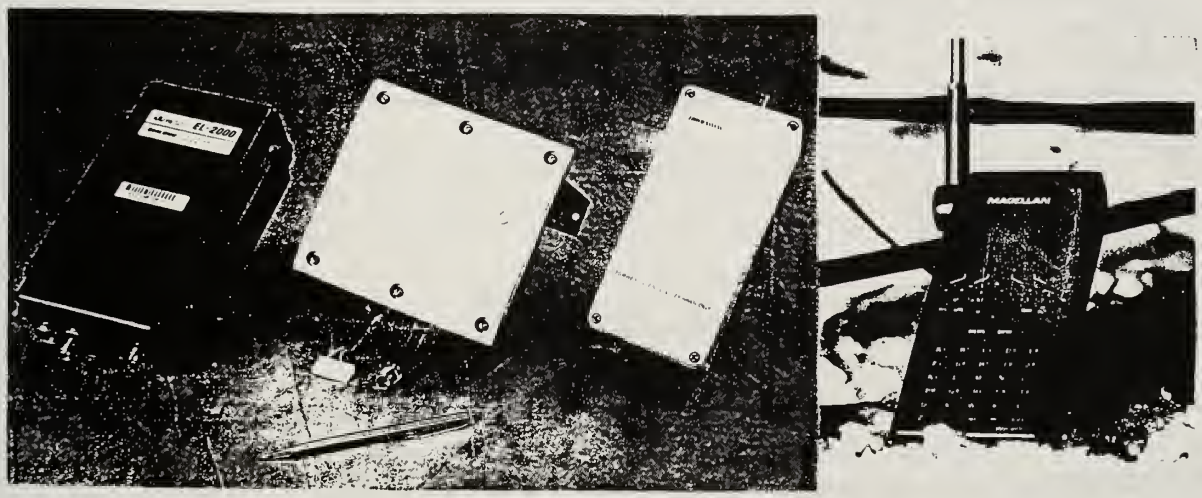

Figure 5.5. Subscriber Communicators advertised by ORBCOMM

The information can be encrypted using end-to-end procedures, by which the information is encrypted by the transmitting SC, transmitted, and decrypted by the receiving SC. ORBCOMM expects that a commercial SC with encryption capabilities will be available in two to three years.

Inside the ORBCOMM network, each SC is identified with a unique address that is activated when the operation of this terminal is authorized. This NCC verifies the address

for every message to certify that the sender and receiver are valid operators. This function allows ORBCOMM to shut down a given terminal simply by eliminating its address from the authorized list, for example if the customer does not pay his or her bills. Table 5.1 provides the SC characteristics.

Table 5. 1. Subscriber Communicator (SC) Characteristics

	Transmit	Receive
Data Rate	2400 Baud	4800 Baud[2]
Frequency	148 -150.05 Mhz	137 -138 Mhz
Modulation	DPSK[3]	DPSK
Power	5 Watts	
G/T[4]		-28 dB/° K

D. CAPABILITIES

The ORBCOMM system will provide two basic services to a user anywhere in the world: digital data communication of small messages up to 256 bytes and position determination.

1. Digital Data Communication

The user will be able to compose, transmit and receive messages on a very small hand-held device or a device integrated with a palmtop computer. The user will only need to point the whip antenna on the Subscriber Terminal (ST) up toward the sky and transmit

[2] Baud is defined as the number of changes in the signal per second that the hardware generates [Comer, 1996]
[3] Differential Phase Shift Keying (DPSK) is a particular type of modulation.
[4] G/T Gain to noise ratio.

the message to a satellite. The satellite sends it to the regional GES, the GES then redirects it to the NCC using leased terrestrial lines or Very Small Aperture Terminals (VSAT). The NCC determines the location of the recipient through the recipient address and routes the message to the appropriate GES. The GES up-links the message to a satellite again. Finally, the satellite down-links the message to the recipient. This entire process takes three seconds. Figure 5.6 illustrates the steps mentioned above.

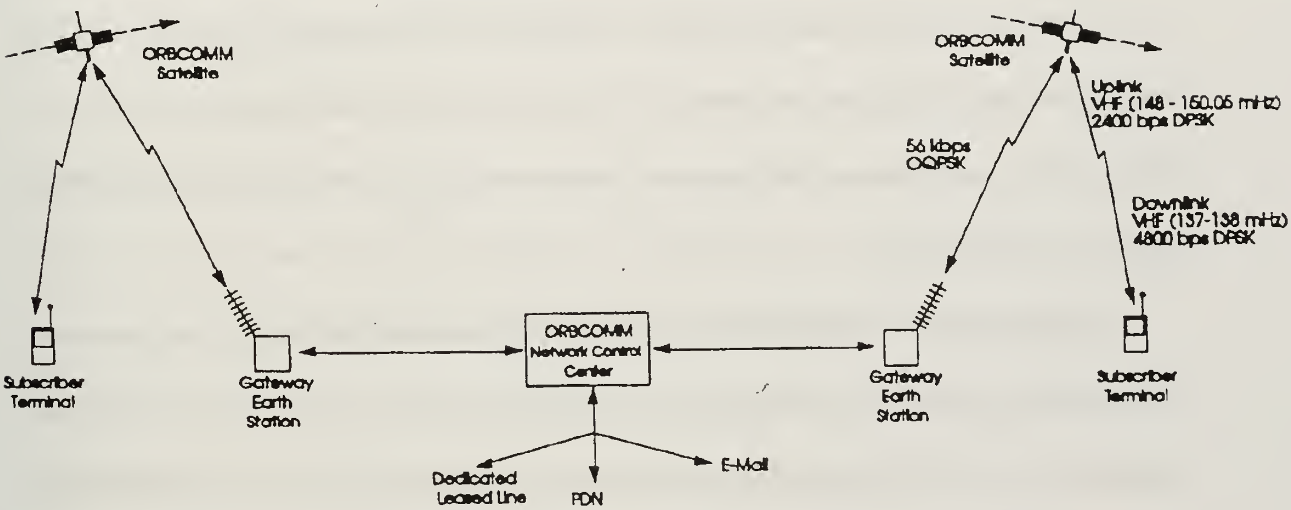

Figure 5.6. Message pathway [Hara, 1993].

However, in order to achieve a three second transmission time, the sender SC, satellite, and GES must be on view and the receiver SC, satellite, and GES must be on view. When the satellite does not have any GES on view, it stores the message and releases it as soon as the first GES appears ("store and forward"). One important drawback is that the packet size is limited to 256 bytes, so this system is limited to small messages. It is possible to send bigger messages but it will be fragmented and may be received in pieces.

At least fifty-two satellites would be needed in the constellation to provide true real-time operation. ORBCOMM rejected this option as economically infeasible. Instead, the system provides what can be considered "near real-time": a wait of no more than five to ten minutes for satellite acquisition. The constellation of twenty-six meets those requirements [Burgess, 1996].

The military user must be concerned about the entire delay time, or the time from the moment the sender is ready to transmit a message to the moment the recipient actually gets the message. This may vary from three seconds, when the conditions are optimal, to many hours when the subscriber does not have the satellite in view and the satellite does not have any GES in view.

Although ORBCOMM does not clearly define how the time required to get at least one satellite in view is computed, the value of ten minutes can be adopted as a maximum reasonable value. Todd Hara, ORBCOMM Senior Engineer, wrote in 1994 (referring to the thirty-six satellite constellation): "The satellite constellation is key to providing the following system performance objectives:

95% availability of spacecraft above 5 degrees elevation to the horizon.

99% of outages (satellite not in view) less than 5 minutes

95% of outages (satellite not in view) less than 2 minutes "[Hara, 1994].

The same year, in another paper, Hara wrote: "With a constellation of thirty-six LEO satellites and terrestrial facilities, the U.S. user will have a satellite in view continuously over 95 % of the time and will have to wait less than two minutes the rest of the time." [Hara, 1994].

In 1995, Anton B. Reut, ORBCOMM Director Government Services, and Todd Hara wrote (referring to the thirty-six satellite constellation): "The system is designed to meet the following system performance objectives in the temperate climate zones in both the Northern and the Southern hemispheres:

98% availability of spacecraft above 5 degrees elevation to the horizon.

99% of outages (satellite not in view) less than 5 minutes

98% of outages (satellite not in view) less than 2 minutes " [Reut, 1995].

Though the statistical values presented by the company are somewhat inconsistent, the graphic representation of satellite coverage for twenty-four satellites at a given instant (Figure 5.2) shows that at medium latitudes, the probability of having at least one satellite on view is high. Therefore, an assumption of 95 % availability appears to be reasonable.

From this point on, I will assume that the worst case condition is when the user must wait ten minutes to get a satellite on view. So, the sender SC may have to wait as long as ten minutes to acquire a satellite (uplink). After the message passes through the NCC and GES, it may take the receiver SC up to ten minutes to acquire a satellite (downlink). So, although rare, it could take as long as twenty minutes to send a message through the system. This significant time delay would be more common where there is not a GES in the operations area.

Suppose the message sent from some part of the South Atlantic Ocean, maybe 400 nautical miles east of Puerto Belgrano,[5] reaches the satellite but there are not a GES on view. The satellite stores this message until it is able to see a GES. We do not know

[5] Puerto Belgrano: The Argentine Navy's most important base, located close to Bahía Blanca, Buenos Aires.

exactly how much time this will take. Let us assume thirty minutes.[6] Then, the message is directed to an NCC and redirected to the satellite and GES nearest to the receiver. The amount of time required to deliver the message to the receiver will depend on how far the nearest satellite must travel to be in view of the GES. If we define ten minutes as "near real-time," this system may not provide even near real-time to some users.

Analyzing again the instantaneous coverage at a given moment for twenty-four satellites (Figure 5.2) we can see how one satellite is covering all of Argentina, Chile, the Atlantic Ocean and the Pacific Ocean. Remember that the coverage circle diameter is about 5460 Km (2948 nautical miles) and the Argentine Navy operations area normally will not exceed 400 nm from shore. With my assumptions stated above, it is possible that a deployed ship might wait ten minutes to acquire a satellite, but when the satellite is acquired it would most likely be on view of the GES located in a central region of Argentina (assuming we have a GES) and in view of the receiver, so we would not expect the delay to exceed ten minutes. Depending on what kind of application we hope to satisfy, ten minutes may or may not be acceptable. A ship can send a tactical message to a deployed unit using ORBCOMM in less time than the required to set up a new HF circuit, but it cannot entirely replace the tactical circuit. If we only considered electronic mail, administrative messages, and distant assets control (like navigation buoys), two, three or more hours delay might be acceptable.[7]

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[6] Thirty minutes is reasonable. considering the satellite will found an appropriate ground station in North America.

[7] The consideration of more than a satellite period (100 minutes) for the time elapsed from when the message is sent until it is received. is based on the assumption that only the U.S. GES already exists. So. it may happen that the satellite must wait more than one orbit to pass again over the U.S. GES. Having the appropriate number of GES's distributed throughout the world will alleviate this problem.

Having a GES in our country would not be sufficient to use the system for military purposes. We would also need a regional NCC to make the system more reliable for two reasons: physical security and information security. Under critical situations we need to reduce the risk of third party country managing our messages and our system. However, although having a regional NCC and our own GES will provide more flexibility, the ultimate control will always belong to ORBCOMM USA.

2. Position Determination

Position determination of an SC will be accomplished using the Global Positioning System (GPS). The GPS receiver on the satellite allows the satellite to calculate its precise position, and acquire precise time information. Using precise time and position information received from the satellite, the user terminal can calculate its own position using the Doppler frequency shift measurement technique. This calculated position (within 500 meters) can be relayed through a satellite (or alternative measurements can be performed on board the satellite at the expense of increasing the traffic loading), giving the user's position to the NCC.

The system also allows each SC to determine its position with more precision by using an integral GPS receiver and communicate this position to the NCC through the satellite and GES [Hardman, 1991]. Of course, this configuration is more expensive.

In summary, ORBCOMM is a commercial system designed to provide:

-Two way non-voice messages with world-wide coverage

-Monitoring and control of remote assets

-Collection of data from hand-held subscriber communicators

It could be useful for many military applications that do not require voice transmission. It is reliable enough to provide simple communications for remote areas, including oceans. Further, because the entire system was conceived and developed to satisfy commercial requirements at reasonable prices, the cost of using it may be acceptable.

E. APPLICATIONS

In order to figure out how Argentine Navy can take advantage of the ORBCOMM system I first looked at some commercial applications that the system was designed for.

1. Commercial Applications

In general, the company advertises different applications like emergency towing systems, emergency medical communications, boxcar and container monitoring, stolen property recovery, trucking monitoring, animal tracking, remote access monitoring, personal business, communications for the impaired, customs and law enforcement. The follow are a few examples:

a. Transportation

The integration of GPS with the communications system provides a useful tool for transportation management. Security and efficiency can be considerably increased by using this system. The SC can be installed in each of the desired trucks, containers, boats or whatever someone wants to keep track of. Appropriately programmed, this SC will send either position or status at a previously scheduled time (daily, weekly, hourly) or when requested. If something happened to the vehicle, or we just wanted to know how

many empty containers were in a distant warehouse, we could get this information simply by asking the system.

b. Remote Monitoring capability

The SC attached to the appropriate sensor can provide the information necessary to take actions that can avoid bigger problems. For example, it can be used to control the flow of oil or gas on pipelines in remote areas, monitor water level of a river to provide a warning of flooding or drought and measure contaminant levels to protect the environment.

c. Safety communications

Under certain circumstances, ORBCOMM could be the most effective way to send a message safely and reliably while limiting the number of listeners. Sometimes the open voice circuits are not desired or the propagation conditions do not allow normal communications. Emergency situations in remote areas can require this service.

d. Commercial and Personal Communications

Some companies can use the system as a way to transmit short messages to their agents located in remote locations. The system can be used as two-way, point-to-multipoint and multipoint-to-point communications covering a wide area Although cellular phones are more common in cities, there is still a gap in coverage in remote regions.

2. Military Applications

ORBCOMM noticed early the "dual-use" policy developed by the U.S. Department of Defense (DoD) as part of the civil-military integration after the Persian Gulf War. The company studied some applications to tempt the U.S. military forces.

Press information released by the company said that in 1995 the ORBCOMM system was "successfully" tested by the U.S. Army. About 1500 messages were transmitted between six different locations during a two week exercise. The system was used to request data from DoD's Global Broadcast System and to confirm its reception. The Army also used it to communicate between two secure communications facilities and to geolocate vehicles [Pizzimenti, 12/09/96]. The word "successfully," in this case must be carefully scrutinized, for the company means that the system worked within the expected parameters and accomplished what they expected it to. However, I am not able to determine how useful this system was to the users. I have no information indicating that the Army or any other military force is using the system other than in that particular exercise.

ORBCOMM developed military applications that include remote asset monitoring, logistics tracking, search and rescue operations, and two way messaging and paging. I think that in same cases, ORBCOMM could be a powerful military tool. It can be either used as a complementary system or used as primary system when deploying personnel in remote areas or frontier locations. Figure 5.7 illustrates ORBCOMM's military applications.

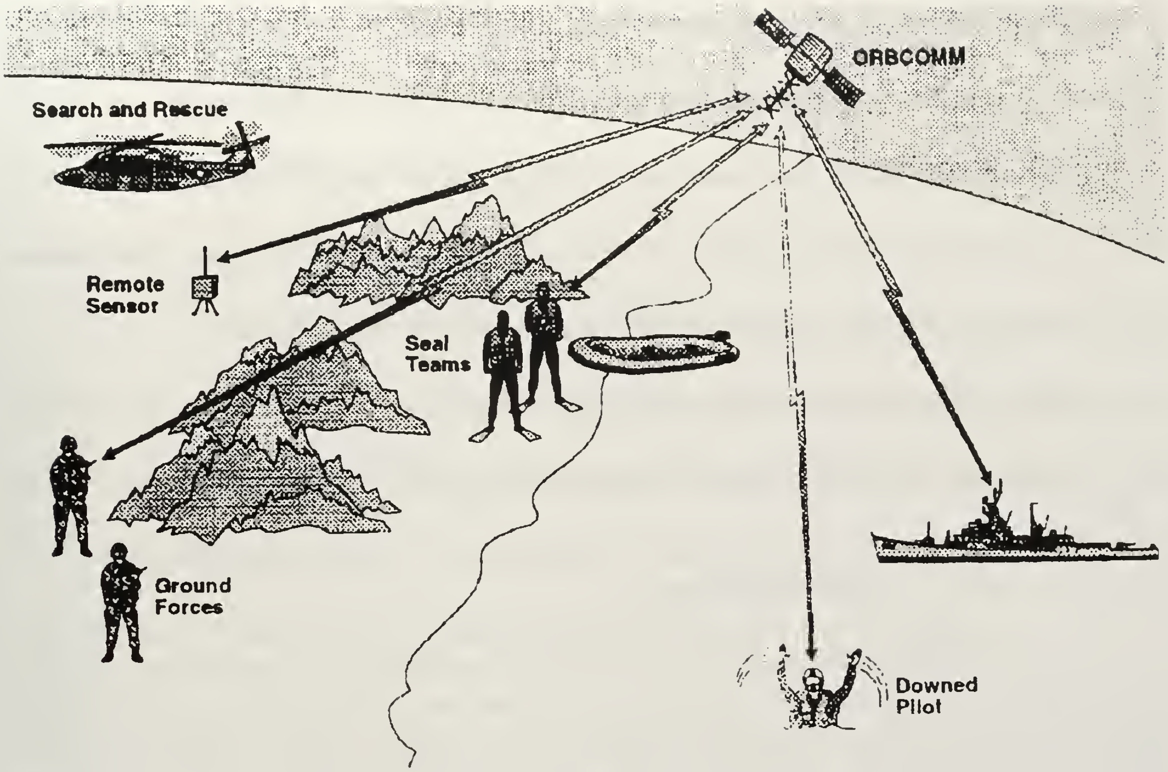

Figure 5.7. Military applications

a. Mission Applications

The ORBCOMM system can provide geolocation with the accuracy of 500 meters based on a combination of Doppler frequency shift provided by the satellite and the satellite's on-board GPS receiver. If it is needed, an optional GPS receiver in the SC can provide higher accuracy (100 meters). This information can be used to keep track of military assets deployed in the battlefield at distant points from the command center.

Because the SC is small enough to carry in an attaché, and the required power is achievable with portable batteries, the system is flexible enough to be used in any operational theater. Other advertised applications include: [Reut, 1995]

-Tracking the positions of logistics items throughout shipment

-Remotely interrogating electronic tags and manifests

-Collecting crucial environmental data from anywhere in the battlespace

-Monitoring the status of remote sensors from the U.S. or field command posts

-Interrogating assets beyond the line-of-sight without terrestrial repeaters or relays

-Inquiring about the status of rapidly moving weapon systems

-Sending and receiving messages at any time

-Providing global search and rescue coverage for downed pilots

b. Asset Monitoring

A SC attached to an asset that military people want to monitor can provide timely status information. The implementation of the specific group of sensors will be driven by the requirements. The SC could be also integrated into the small local weather station so it could provide environmental information to the regional command or operational base so that it can aid decision makers.

ORBCOMM is still planning to conduct beta tests (tests intended to probe capabilities). One of those tests is the integration of SC's into the existing drift buoys. Using the buoy's existing housing, antenna and power supply, it could be possible to transmit the environmental data collected by the buoy (barometric pressure, air and sea surface temperature, and current).

c. Logistics

The tracking capabilities previously mentioned for commercial transportation could be applied to military movements. Using the system, it could be

possible to know exactly where our supplies are and promptly detect when something has altered our plan. Also, if we are awaiting a critical spare part coming from a distant location, we could track it throughout the entire trip to be sure it does not get delayed or sent to the wrong place.

ORBCOMM is planing various tests in order to satisfy potential military requirements. One of them is directed toward tracking and monitoring the location and status of people, supplies and weapons systems. From the point of view of the Commanding Officer, who has a force deployed in distant areas, it could solve one of the basic questions: Where is my personnel and material and how are they doing?
ORBCOMM is still developing the system and exploring applications. Any military user considering the use of this system should establish their own needs and determine the specific limitations of the system.

3. Possible Argentine Navy Applications

a. Maritime Traffic Control

One of the basic missions assigned to Navy ships at sea is maritime traffic control. The traffic information is compiled by the Maritime Traffic Control Command based on the daily position messages the ships at sea must send. By using ORBCOMM SC's these messages could be automated and increased in frequency, if necessary. For big ships, the approximate cost of 1,000 dollars for the equipment and small monthly fee can be an insignificant expenditure. For small boats or cruisers it could be a desirable alternative to have a communication system, although limited, to communicate with a Cost

Guard for emergencies or for sending special request when out of range of normal VHF radios.

One of the problems detected in controlling fishing ships is that they protect their position to avoid saturation when they find a productive area, which creates difficulties for meteorological warnings and search and rescue actions. Using the ORBCOMM system, the owner of the company can safely receive the position and status of its ships and the authorities can maintain control of the situation.

b. Small boats operations security

There could be an operational scenario in which we have to send a small boat on a silent mission. If the capital ship is unable to wait until the end of the mission and the people must be recovered by another ship. A hand-held SC can provide additional security to the crew of the small boat and appropriate feedback to the Commander Officer so that he can recover his people at the right time in the right place.

c. Search and rescue

The SC on board a damaged ship or plane can send and emergency message at the last second that provides the last accurate GPS position, thereby simplifying the search and rescue operations. On board a lifeboat, it can provide much more help than other systems we had before, enabling survivors to send not only their position but also the condition of the injured people. Medical units can be dispatched immediately and the psychological health of the crew can be keep stabilized while waiting

to be rescued. A pilot who is downed over hostile territory would have a higher probability of surviving and being rescued.

d. Ship to ship administrative and limited tactical messages

Sometimes small administrative or tactical messages are needed and the propagation conditions of the radio signal turns this need for communication into a vulnerability. Unjustified repetitions can be avoided by using the ORBCOMM system. We can reduce our broadcast time and thereby reduce the probability of being detected and monitored. Remembering that VHF is line-of-sight (LOS) and cannot propagate beyond the horizon, the probability of interception of the sender message is reduced, but the probability of the interception of the satellite relayed message is increased, though encryption can reduce this somewhat.

e. Maritime signals control and maintenance

A secondary duty assigned to some Navy units is the control and maintenance of maritime signals. In some remote regions the monitoring capability can help keep track of lighthouses or buoy status.

f. Oceanography

The U.S. Naval Research Laboratory at Stennis Space Center will use the ORBCOMM system in conjunction with the AN/WSQ-6 class of Navy Mini Buoys. These buoys are deployed in remote areas and can provide meteorological information on a regular basis or by request. Similar devices can be designed to be attached to remote

sensors that can keep yearly track of the environmental changes, for example, in the Antarctic.

g. Battlefield tactical messages

Depending on the friendly and enemy forces deployed and the urgency of the action, the system can also provide a method of communication that is much less vulnerable to interception than conventional open circuits.

h. Peace Mission Communications

The portable, cheaper, world-wide coverage SC's can link small deployed forces with their home command. Also, a detached ship can use it to significantly reduce the cost of its administrative messages. The cost of the INMARSAT system to send one minute fax is around six dollars, and the ORBCOMM advertised cost is about one dollar per message of 256 bytes.

F. BENEFITS AND DISADVANTAGES

1. Benefits

a. No development is required

We can use ORBCOMM services without having to develop the satellite system and the associated equipment. We can acquire ORBCOMM services on a commercial basis at the same prices as civilian customers.

b. Non-LOS communication

From a tactical point of view, there is a powerful element to be considered. The system can provide non-LOS communications. Other satellite systems require the deployment of more complicated antennas to establish communications. Traditional HF requires more radiated power and is easily detected.

c. Small equipment required

The SC is the only equipment required to operate the system. It is small, cheap, portable, and water resistant, so it could be use on board a small boat or by Marine Corp Units.

d. Competitive commercial product

Different manufacturers are developing compatible terminals so the competition may make the product better and future prices cheaper. The available SC's can be acquired for $ 700 to $1,000, depending on the final configuration. ORBCOMM is a profit-driven organization interested in selling its product, so virtually any operation or configuration can be acceptable, if it represents money for the company.

e. Communications may be encrypted

The security of the system can be increased by using traditional encryption systems.

f. Low power required

The SC only requires five watts, which makes it portable and low in power consumption.

g. Priority may be assigned

The NCC classifies the messages in four different priorities, so military messages could be given priority over other civilian users of the same system.

h. Robustness and redundancy

Robustness and redundancy of the system is accomplished by the large number of satellites, so the failure of one satellite would not significantly affect the performance of the system.

2. Disadvantages

a. No real time

It is not real time. For some applications, like electronic mail, this would not be considered a drawback.

b. Non-voice system

It is by design a non-voice system.

c. Very controlled network

It is a very controlled network. It does not matter where the sender and receiver are when generating messages. The sender and receiver can be very close to each other, but the message must travel through the GES and NCC. During this process, the

address and the position of the sender and receiver are computed in order to determine the route the message must follow, so the position of a ship sending a message will be known by NCC. If we had our own NCC, this will probably not be a problem, because we may restrict the access to this information. However, if just happened that the GES directs the message to other nation's NCC, accurate vital information can be provided to the hypothetical enemy. How this situation may happen needs to be figured out in advance and it will probably depend on the NCC locations distributed around the world. This problem can be avoided having our own NCC and GES. It also creates so much dependence on the ground segment, which is vulnerable to intentional damage.

d. ORBCOMM may shut down the service unilaterally

The service can be shut down by ORBCOMM unilaterally. Although this action could hurt the company, under international conflict situations, ORBCOMM, being an American corporation, will probably respond to the U.S. Government pressures.

Under the existing conditions, keeping in mind that our policies are intended to strengthen the North-South relations, and our missions are more closely related with the United Nations interests than ever, the possible shut down is highly improbable, but must be considered. ORBCOMM can deny access to a particular address as we mentioned before and also has the capability to deny the appropriate codes to an NCC, hence closing its operation. By contrast, the owner of GPS (the U.S. Military) is unable to control the receivers, so the only way to deny information to an undesired user is by modifying the satellite information, which affects all users, friendly or otherwise.

e. Low transmission rate and limited capability

It has a very low transmission rate (transmission 2400 bps; reception 4800 bps). Total transmission capability is 61,000 fifty byte messages per hour, and the normal message should be no longer than 256 bytes. If it is larger it must be split into packets, which are sent through the network separately.

f. Non-established in Argentina

Argentina does not have an ORBCOMM sales representative nor does it have an NCC or GES. The representative in Argentina and Uruguay (ORBCOMM del Sur) is no longer affiliated with the company. However, to minimize local legal problems, ORBCOMM Global, L.P. (Responsible for the international business) has signed agreements with different communication companies from other nations to act as resellers of its services. Hence, different ORBCOMM subsidiaries were created to provide services to different countries, but this is still an ongoing process. ORBCOMM is interested in the Argentine market and is looking for another serious communication company to manage the region, so we may expect that as the system grows we will have a civilian company operating ORBCOMM in our region.

G. FINAL CONSIDERATIONS

The basic capabilities of the ORBCOMM could be exploited by the Argentine Navy on a commercial basis. As I mentioned in Chapter II, the contribution of space assets to the military field is directed to improve C^3I/C^4I capability. Can this system contribute to improve C^3I/C^4I architecture of the Argentine Navy? The answer is yes. We

can see in the U.S. forces that the entire C^4I is not build around a single, dedicated military system but around many different systems capable of satisfying diverse requirements. During the Gulf War, U.S. forces realized that the dedicated military satellite systems were unable to manage the vast information needs. After that, the use of commercial systems by the military drastically increased and civil-military integration began to emerge.

For our case, we can assume that ORBCOMM non-voice communications can complement our basic structure, but could never be considered a primary tactical system. Adequately implemented, the ORBCOMM system could satisfy many applications and can provide good help to the Argentine Navy basic missions. Nevertheless, we will always need to consider alternative ways to do the same thing.

Like other civilian systems, ORBCOMM is not prepared to support aggressive actions that can be conducted during war time (it is vulnerable to jamming and ground segment dependent). ORBCOMM is more appropriate for logistic support or peace-time deployments than for tactical operations in the battlefield.

VI. MILITARY APPLICATION OF COMMERCIAL IMAGERY SYSTEMS

A. INTRODUCTION

As it was recognized with the release of Corona Program information,[1] the observation of the earth from space was of much interest during the Cold War era. Photographs from the first manned space missions stimulated the intelligence community's interest. These photographs also stimulated commercial and scientific interest. The scientific community looked forward to studying what could have only been possible to learn from space. The first civilian space remote sensing program was *Earth Resources Technology Satellites (ERTS)*. Initiated in 1967, the ERTS resulted in a planned sequence of six satellites. After the second successful launch, it was renamed by NASA as the LANDSAT program (to distinguish it from the planned Seasat oceanographic satellite program). [Lillesand and Kiefer, 1994]

The Open Skies[2] policies went along with the development of what evolved into LANDSAT. Although initially classified, imagery from the LANDSAT program was approved for general release to the public and became the most powerful tool at that time for earth studies. In spite of its primitive technology and limited capabilities and resolution, relative to what we have today, it gained global acceptance, and fourteen

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[1] Corona was the first American spy satellite developed during the government of Eisenhower (1952-1960) [Brugioni, 1996].

[2] The "Open Skies" principle means there would be nondiscriminatory access to data collected anywhere in the world [Lillesand and Kiefer, 1994].

countries, including Argentina,[3] obtained licenses to build LANDSAT ground stations, making it the first commercial imagery in the world.

The decision for sell LANDSAT imagery was based on three factors. First, the scientific community's demand for imagery had increased over the years. The earliest data obtained from photographic cameras mounted on balloons was improved with the advent of the airplane. The accumulation of archives allowed scientists to document surface features and their changes. They discovered the importance of having more information and the capability to assemble assembling different data sets in order to provide information to diverse fields like agriculture (vegetation and crops health), mining, and oil explorations.

Second, selling LANDSAT data gave the U.S. a way to reduce cost and increase capacity. Because the satellite did not have on-board storage capacity, the only way to get information about a particular area was through a ground station in close proximity to the area of interest. Areas not having a ground station within about 3000 Km could not be imaged. By sharing LANDSAT data, the U.S. could get access to the information obtained by ground stations located in other countries.

Third, and probably the most important, was the ability of the U.S. to maintain control of the information. The information could be denied simply commanding the sensor off from the main control station. Of course, this would affect all users, friendly or otherwise. [Lee, 1994]

[3] The Argentine ground station was deactivated in 1985 for economic reasons. Our users now buy images directly from LANDSAT, SPOT and the Soviet Systems [Dominguez, 1991]

The commercialization of French *Systeme Pour l'Observation de la Terre* (SPOT) Imagery, starting in 1989, marked the end of the U.S. monopoly. The U.S. is no longer the only owner of commercial space capabilities and technology. The other major player, Russia, who had remote sensing systems for years, and who had never disputed American leadership in remote sensing, is completely changing its policies. It is trying to convert its military programs to commercial ones.

First of all, we must recognize the sensitive and highly classified nature of space-based military and intelligence collection systems. But, what happens when a similar system developed by a civilian organization is able to provide the same or better capabilities without restrictions?

It is important to understand that with recent advances in space technology and computer processing systems, remote sensing information is getting more easily obtainable and understandable. SPOT Image Corporation, for example, openly advertises the intelligence gathering and military utility of SPOT imagery. The company recommends different applications in that area and also recommends the appropriate software for better use of this imagery. [Paige, 1996]

The initiation of international competition in remote sensing products accelerated development of the field. The satellite remote sensing industry has grown significantly since 1960. 1994 estimates established the market at $275 million with the expectation of reaching $2 billion by the year 2000. Thirty-six commercial remote sensing satellites are planed for launch from 1997 to the year 2009. [Deans, 1996]

I believe the Argentine Navy should start seriously considering the use of commercial remote sensing imagery, because remote sensing imagery have many applications that can help our Navy to accomplish its basic missions (mission planning, trafficability, navigation, weather, intelligence, mapping). Further:

-We are not yet capable of getting our own military remote sensing assets

-Commercial remote sensing proved very useful during the Gulf War. During the Desert Storm, U.S. military remote sensing systems were not enough to satisfy all allied needs. Commercial remote sensors like SPOT and LANDSAT were used, and better resolutions could have been used, if available

-It is better to have something with limitations than nothing at all. At this point I consider that commercial remote sensing is better than nothing.

-It is available, and as well as we can use it against our hypothetical enemies, they can use against us.

-It is a tool that more advanced military countries like the U.S. are using on a daily basis. If we are willing to cooperate and take part in international missions, for example, peace keeping or anti-narcotic operations, we need to at least understand what they are doing.

Today, the conditions to start using commercial remote sensing in the Argentine Navy are better than they have ever been. The global commercial remote sensing industry is experiencing competition that is making its products cheaper and better. Argentine international policies are characterized by a clear alignment with the U.S. and its allies. Continuous military participation in peace keeping missions has permitted the achievement

of international recognition. Proof of that is that an Argentine Army General is today commanding a peace keeping mission in Chipre, which is integrated with Great Britain and Argentine soldiers [Clarin, 1997]. These reasons will play in our favor, if some voice were lifted against us with respect to a particular remote sensing application.

B. PARAMETERS TO CONSIDER IN THE USE OF CIVILIAN REMOTE SENSED DATA

To understand the military applications of the civilian systems, it is necessary to keep in mind the parameters that make the remote sensing imagery useful. These parameters are spatial resolution, spectral resolution and timeliness.

1. Spatial Resolution

Spatial resolution is the minimum size of an object on the ground that the sensor can distinguish. For example, a satellite having ten meter resolution will not be able to distinguish an object that has a characteristic dimension of less than ten meters. Spatial resolution determines the satellite's ability to accomplish tasks such as detection, general and precise identification, description and technical analysis. Table 6.1 provides detail about which resolutions are needed to accomplish these tasks for different targets.

It is interesting to notice that one meter resolution is almost good enough to provide precise identification for most of the targets that represents valuable tactical information. This kind of resolution will probably be commercially available in a couple of years, but other parameters need to be considered before assuming that it will be tactically valuable.

2. Spectral Resolution

Spectral resolution is the ability to discriminate fine spectral differences. Objects of interest usually radiate or reflect different values of energy at different wavelengths. By using several spectral bands in the observation of the same object, it is possible to recognize some features that are not visible in a normal panchromatic (what the human eyes sees) photograph. For example, healthy vegetation can be clearly distinguished from dead or stressed vegetation using near infrared wavelengths (.8 - 1.1 μm), which are beyond the range of human vision. Healthy vegetation, while appearing green in conventional color photographs, will appear in red hues in color infrared photographs because of the elevated near-IR reflectance from the mesophilic tissue of the leaves. Stressed vegetation also appears green in conventional color photographs, but appears pink in near-IR photographs. Dead vegetation appears yellow in conventional color photographs, but appears white in near-IR photographs. Table 6.2 shows the spectral bands on SPOT and LANDSAT satellites, along with some of their applications.

3. Timeliness

This parameter is probably the most difficult to improve when using commercial imagery. It depends on three factors: revisit frequency, which is the time it takes the satellite to pass over the same point twice; imagery processing time; and image delivery time.

Table 6.1. Ground Resolution Requirements for Object Identification (in meters) [Lee, 1994].

Target[a]	Detection[b]	General ID[c]	Precise ID[d]	Description[e]	Technical Analysis[f]
Bridges	6	4.5	1.5	1	0.3
Communications					
Radar	3	1	0.3	0.15	0.015
Radio	3	1.5	0.3	0.15	0.015
Supply Dumps	1.5	0.6	0.3	0.03	0.03
Troop Units (in Bivouac or on Road	6	2	1.2	0.3	0.15
Airfield facilities	6	4.5	3	0.3	0.15
Rockets/Artillery	1	0.6	0.15	0.05	0.045
Aircraft	4.5	1.5	1	0.15	0.045
C^2 Headquarters	3	1.5	1	0.15	0.09
SSM/SAM Sites	3	1.5	0.6	0.3	0.045
Surface Ships	7.5	4.5	0.6	0.3	0.045
Nuclear Weapons Components	2.5	1.5	0.3	0.03	0.015
Vehicles	1.5	0.6	0.3	0.06	0.045
Land Mines	9	6	1	0.03	0.09
Ports and Harbors	30	15	6	3	0.3
Coasts/Beaches	30	4.5	3	1.5	0.15
Rail Yards and Shops	30	15	6	1.5	0.4
Roads	6–9	6	1.8	0.6	0.4
Urban Areas	60	30	3	3	0.75
Terrain		90	4.5	1.5	0.75
Surfaced Submarines	30	6	1.5	.1	0.03

[a]Chart indicates minimum resolution in meters at which target can be detected, identified, described, or analyzed. No Source specifies which definition of resolution (pixel-size or white-dot) is used but the chart is internally consistent.

[b]Detection: Location of a class of units, object or activity of military unit.

[c]General Identification: Determination of general target type.

[d]Precise Identification: Discrimination within a target group.

[e]Description: Size/dimension, configuration/layout, component construction, equipment count, etc.

[f]Technical Analysis: Detailed analysis of specific equipment.

Table 6.2. LANDSAT and SPOT Spectral Band Applications (in microns) [Lee, 1994].

Landsat	SPOT	Application
.45–.52 (Blue light)		Coastal water mapping soil/vegetation differentiation deciduous/ coniferous differentiation
.52–.60 (Green light)	.50–.59	Green reflectance from healthy vegetation iron content in rocks and soil
.63–.69 (Red light)	.61–.68	Chlorophyll absorption for plant differentiation
.76–.90 (Near-Infrared)	.79–.89	Biomass survey water body delineation
.80–1.1 (Mid-Infrared)		Crop vigor
1.55–1.75 (Mid-Infrared)	1.58–1.75	Plant moisture content cloud/snow differentiation
2.08–2.35 (Mid-Infrared)		Soil analysis
10.4–12.5 (Thermal Infrared)		Thermal mapping soil moisture

For example, suppose we are using SPOT imagery and request a Standard Full Scene (37 x 37 Mile) Panchromatic (ten meter resolution) image at nadir viewing conditions, covering a particular area of interest, and centered about a given latitude and longitude. Assume that you can make the request immediately after making the decision to acquire the imagery, and your desired photograph is not in the SPOT archive. Since the SPOT revisit time is 26 days, the worst condition is that the satellite has just passed and you need to wait 26 days to have the satellite over the right position again. The best

condition could be that the satellite is about to pass over the area of interest and SPOT has sufficient time to command the satellite to collect your desired image. Once obtained, the data must be processed based on your initial requirement. This normally takes about a week. Then data is delivered in the appropriate format, let us assume CD ROM. For imagery that is already in the archive the established turn-around times are: twenty days (Standard), ten days (Urgent) and three days (Rush). Table 6.3 shows how the maximum and minimum expected delivery times may vary. "Delivery time" here is defined as the time that elapses from when we establish the requirement until we receive the desired information.

Table 6.3. Example of Timeliness for SPOT satellite (Time in days).

Time to Revisit	Time to Process	Delivery	Delivery Time
26	7	20	**53**
26	7	10	43
26	7	3	36
13	7	20	40
13	7	10	30
13	7	3	23
1	7	20	28
1	7	10	18
1	7	3	**11**

Note that for the assumed delivery parameters, revisit time is only function of how lucky you are when you make a request (if the satellite just passed, you will have to wait twenty-six days; if it is approaching to the desired position, one day; in the middle of the revisit cycle thirteen days). If we owned the satellite, or even an authorized ground

station, we may decrease the required time to process and deliver the imagery, but we can do nothing about revisit time.

C. MILITARY APPLICATIONS [OTA- ISC-558, 1993].

1. Military Operations

Although the U.S. DoD has been buying LANDSAT and SPOT imagery for years, it was during the Gulf War that the public and the politicians realized how important this capability was. The international embargo against Iraq denied the use of SPOT imagery to Sadam Hussain, which Iraqi forces had used to invade Kuwait. On the other hand, the Coalition Forces used LANDSAT and SPOT imagery to create a variety of maps of the desert. Also, LANDSAT and SPOT imagery was used to create maps of Bosnia, which were used for mission planning in delivery of food and medical support.

One clear example of how this information can be used is the product developed by Cambridge Research Associates called PowerScene™. Power Scene™ is a computer simulator that allows the user to recreate, at the resolution of the provided information, a three dimensional model of a desired area, so a pilot can go through it in a flight simulator and see and learn point by point, feature by feature, meter by meter, the path to the target, from the beginning to the end of the mission, with accurate precision. Such a tool provides a huge difference in training and planning. Before flying the mission the pilot can "fly" it as many times as he needs on the computer, recognizing the weaknesses of the enemy and having an accurate assessment about dangerous areas and effective ranges of enemy weapons. [Pentecost, 1996]

2. Reconnaissance

The basic concept that resolution is the limiting factor of what can be obtained from the space imagery is not as true as seems. Skilled interpretation combined with the use of information obtained by other means can add more value to the imagery [Brugioni, 1996]. In other words, the difference between useful information from reconnaissance satellites and useless imagery is a trained interpreter.

The chief problem in reconnaissance is the time we need to wait between two passes over the same point. For example, LANDSAT satellites pass over a given place along the equator once every sixteen days, and SPOT once every twenty-six. In addition, it takes about two weeks for SPOT to process the information and send it to the customer. From the military point of view, we need the information as soon as possible, and two weeks is unacceptable in some cases. Processing and delivery could be shortened by having an authorized ground station in our country. Directional capability of some sensors (for example, SPOT cross-track imaging) reduces time between visits, allowing revisit times at targets of interest every 1 to 4 days.

3. Arms Control

Where nuclear weapons are developed, stored or tested, some characteristics can be observed from the space. For example, the need of large amounts of water to cool the nuclear plants, specially cleared roads with progressive curvatures to allow transportation in and out, or an unusual number of workers in an isolated area Politicians need this

information to activate the mechanisms to enforce international treaties or to take preventive actions. [OTA-BP-ISS-168, 1995]

4. Mapping, Charting and Geodesy

Maps and charts usually require more precision when they are going to be used by the military. Simulations can only be as accurate as the map measurements. Although we speculate that military satellites are able to provide better resolution than commercial satellites (probably less than one meter), merging civilian and military information can save time and money. It is convenient to remember that the U.S. has automated weapons which need to be accurately guided, so an accurate the target position becomes very important.

D. INTERNATIONAL REGULATIONS

Can we use civilian space assets for military purposes? What are the limits for a nation that wishes to use space remote sensing?

We already know that the U.S. and Russia developed remote sensing capabilities to spy on each other during the Cold War, and we can speculate about how big or small this capability currently is. We also have an idea about what other countries like China are doing to gather intelligence from the space [Lee, 1994]. This activity was normally denied, and the international agreements made by the spy satellite owner countries were directed to allow the use of these space assets. For example, invoking the need for "National Technical Means" to verify nuclear arms control treaties.

The use of commercial remote sensing in the intelligence arena is relatively new and is open to the most nations. The U.S. Land Remote Sensing Commercialization Act of 1984 established LANDSAT commercialization on a non-discriminatory basis.

The United Nations Principles Relating to Remote Sensing of the Earth from Space ("The Principles") are contained in a 1986 resolution adopted by the U.N. General Assembly. As a resolution, The Principles are not legally binding but do provide the basis for a multilateral treaty. This resolution is based on the Outer Space Treaty 1967, the Registration Convention of 1976, and the Liability Convention of 1972. The points that The Principles reinforce are:

-Celestial bodies and outer space are the "province of all mankind," and the exploration and use of space should benefit all nations.

-International cooperation is encouraged.

-Nations can claim damages caused by space assets belonging to other nations.

-Every launch must be registered with the U.N.

-The U.N. Secretary-General's role now includes being informed of U.S. remote sensing activities and the U.S. must make relevant information available to other nations upon request.

-"Sensing States" operate remote sensing systems, and "sensed states" are the ones whose territory is observed.

-Data obtained by sensing states should be available to the sensed state on a non-discriminatory basis.

-Sensing states are obligated to avoid harm to sensed states.

The 1986 U.N. principles on remote sensing express an international ideal for the use of remote sensing, although observers disagree about how these principles should be interpreted. The Principles embody the view that outer space is a resource for all humanity and should be used for the general benefit of all nations. [OTA-ISS-604, 1994]

In general, the resolution addressed the basic aspects of using remote sensing. It is important to note that all uses were considered from the scientific and technological point of view, but military applications were not expressly forbidden. Until this point, only classified military programs were considered useful for military purposes, and nobody but the involved nations knew about them. Probably just a few considered at that time the possibility of using civilian remote sensing for military purposes. The only unclassified remote sensing (RS) program (LANDSAT) was not good enough to satisfy more than broad strategic military requirements, and SPOT was just starting as an experimental program. I believe that the introduction of SPOT imagery in the international market really broke down the U.S. dominance and facilitated access to space information for many nations unable to develop their own capabilities. Today, Russia is offering five meter resolution from Resurs satellites (film canister), and India offers RS information to the market at competitive prices. When someone buys imagery, they do not have to mention the reason why the information is required. If it were, the true intention could be masked. Table 6.4 shows the relationships between civilian and military applications.

Legally speaking, we can see that there are different national regulations with respect to selling remote sensing imagery to other countries For example, the Clinton Administration established a regulatory process for civilian companies trying to obtain

licenses for the commercialization and operation of private remote sensing systems. The objective of this policy is to keep control over these companies in order to preserve the U.S. national security. With respect to the export of remote sensing systems or the transfer of "Sensitive Technology," which includes high resolution remote sensing products, the U.S. Government only wants them to be made available to foreign governments through government-to-government agreements. [OTA-ISS-607, 1994]

Table 6.4. Civil / Military Uses of Multispectral Imagery

Civil Application	Military Application
Soil features	Terrain delineation Attack planning Trafficability
Surface temperature	ASW support Trafficability Air field analysis
Vegetation analysis	Terrain delineation Camouflage detection
Clouds	Weather Attack planning
Snow analysis	Area delineation Attack planning
Surface elevation	Mapping, Tercom
Ice analysis	Navigation ASW support
Water analysis	Amphibious assault planning
Cultural features	Targeting, BDA

We can expect that in the next two or three years, many companies will offer commercial remote sensing with as high as one meter resolution panchromatic, and this imagery will be available to Argentina, as well as to our neighbors, on a non

discriminatory basis, but always under the ultimate control of the nation providing the imagery.

In summary, I want to point out two important concepts:

-The first concept is a fundamental truth of international law: If an act is not specifically prohibited, then it is permitted. International law implicitly permits military support activities such as satellite remote sensing, navigation, communications, and meteorology.

-The second concept is that, in most instances, treaties are designed to regulate activities between the signatories during peacetime only. Unless the international agreement clearly states that its provisions are designed to apply or to become operative during hostilities, they must presume that armed conflict will result in the suspension or termination of the treaty's provisions.

E. BENEFITS AND DISADVANTAGES OF USING COMMERCIAL REMOTE SENSING

1. Benefits

a. Reduced Cost

Although not cheap, considering that the average price of just one 60x60 Km picture could be about $3000, it is less expensive than developing the entire system to provide similar capability. To offer a perspective, the LANDSAT 7 (expected to be launched in 1998) DoD budget was about 460 million dollars from 1992 to 1997, plus 2 million dollars in annual operational costs.

The Argentine Republic covers about 2,800,000 Km^2, and each SPOT standard picture (60x60 Km) covers 3600 Km^2, so 780 pictures would be required to cover the entire country. Assume that we need two complete sets of pictures in a five year period. So, 1560 pictures at 3,000 dollars each would cost 4,680,000 dollars. This is less than 1.5 % of the cost of the LANDSAT 7 system. The Argentine Navy's hypothetical needs define an area limited to a littoral strip about 3300 Km length and 120 Km wide (over land), or 396,000 Km^2. One hundred and ten pictures could be enough to satisfy a basic requirement (approximated 330,000 dollars).

b. Capability

From the military point of view, considering our present lack of remote sensing capability, we can acquire a very useful new one by using remote sensing information to support military operations in different ways. Mission planing, reconnaissance, mapping, charting and geodesy, prevention and evaluation of disasters, and trafficability.

c. Experience

If we decided to build or buy our own remote sensing system, we must first understand what is really useful, what requirements the system would be able to satisfy, what the minimum acceptable performance would be, and how this advanced technology is used. By the initial acquisition of commercial remotely sensed imagery (panchromatic and multispectral) and the appropriate software, we can start learning and gaining

experience before developing or buying systems we do not need or that we do not know how to use.

d. Waiting Time

It will take more time for our country to put a one meter resolution sensor in space than to buy the amount of pictures needed to fulfill our possible requirements. Just as we can buy panchromatic imagery with ten meter resolution today, we will be able to buy panchromatic imagery with one meter resolution in a couple of years.

e. Compatibility with allied nations

The use of commercial remote sensing in the military is seriously being considered for nations that already have significant remote sensing capability. Civilian remote sensing systems satisfied some U.S. military needs in the Persian Gulf War, which is probably why the U.S. government wants to have civilian companies making money and able to satisfy U.S. military needs when required. Hence, if the Argentine Navy is able to understand the same remote sensing principles and practices as the U.S., we will be better prepared to work together, as well as with other allied nations.

2. Disadvantages

a. Availability

By using imported commercial imagery, we can not be sure the information will be available when needed, so we must assume that it would not be available in near real time. It will depend on what type of military requirement we have to satisfy in order to say whether or not two-week-old information is useful.

b. Reliability

The issue of whether or not the image can be altered by a third person needs to be considered, especially if we want to use this information during crisis situations. How can I be sure that a certain picture was acquired at the stated period of time and not a year or month ago? For example Israel started its space program in 1988 as a sign of discontent with the U.S., suspecting that U.S. withheld satellite imagery prior the Yom Kippur War.

c. Dependence

The buyer must always depend on the imagery provider's national policies. Without being an owner, the U.S. used SPOT information against Iraq, while the same information was denied to Iraqi forces. France of course was part of The Coalition.

d. Security

On a nondiscriminatory basis, a nation can buy information about its neighbors and vice versa, so the information flow is unrestricted. Although the confidentiality of the buyer should be protected, it is not possible assure that it will happen.

F. EXISTING COMMERCIAL SYSTEMS - OVERVIEW

In addition to the U.S. and Russia, only a few countries have developed capabilities in the remote sensing area; some of them for military purposes, others for scientific or commercial purposes. In RS, it is very difficult to perfectly define whether the conception of the system was military, civil or both. The current leader in commercial

imagery from space is the French Systeme Pour l'Observation de la Terre (SPOT), offering to the international market ten meter resolution panchromatic, worldwide coverage with no political constraints. It was used during the Gulf War by Iraq (until the embargo) and by the U.S. forces. United States, France, Russia, Canada, Japan, India and the European Union are the only providers of commercial remote sensing products. Table 6.5 gives a summary of systems and their products.

Table 6.5 Current International Commercial Remote Sensing Capabilities [Deans, 1996]

Satellite	Sensor	Resolution	Delivery Time	Availability
LANDSAT	E-O[4] Multi-Spectral	30m	2-3 Weeks	1972
AVHRR (TIROS)	E-O Multi-Spectral	1 km	1-2 Weeks	1960
SPOT	E-O Panchromatic	10 m	2-3 Weeks	1986
	E-O Multi-Spectral	20 m		
KOSMOS (KVR-1000)	Film Panchromatic	2 m	3-6 months	1996
Almaz	SAR	15 m	Archive	
RESURS	E-O Multi-Spectral	170 m	3+ Weeks	1994
Radarsat	SAR	8 m	5 - 10 Days	1995
JERS-1	E-O Multi-Spectral	18 m	2 - 3 Weeks	1992
	SAR[5]	18 m		
IRS-IC	E-O Panchromatic	6 m	2 - 3 Weeks	1995
	E-O Multi-Spectral	24 m		
IRS-P2	E-O Multi-Spectral	20 m	3+ Weeks	1993
IRS-1A/1B	E-O Multi-Spectral	36 m	3+ Weeks	1988
ERS 1 & 2	SAR	Variable	2 - 3 Weeks	1991

[4] E-O stands for Electro-optical.
[5] SAR stands for Synthetic Aperture Radar.

1. LANDSAT Series

The LANDSAT series consisted of six satellites, LANDSAT-1 through -6. LANDSAT-6 failed during launch. Satellites -1, -2, and -3 are no longer in service. The LANDSAT-4 and -5 orbits were corrected from their original orbits by lowering the altitude from 900 Km to 705 Km with the dual purpose of increasing resolution and making the satellites retrievable by the Space Shuttle. [Lillesand and Kiefer, 1994]

The following tables (6.6, 6.7, and 6.8) describe the essential characteristics of the LANDSAT program.

Table 6.6. Characteristics of LANDSAT-1 to -6 Missions [Lillesand and Kiefer, 1994].

Satellite	Launched	Decommissioned	RBV Bands	MSS Bands	TM Bands	Orbit
Landsat-1	July 23, 1972	January 6, 1978	1,2,3 (simultaneous images)	4,5,6,7	None	18 day/900 km
Landsat-2	January 22, 1975	February 25, 1982	1,2,3 (simultaneous images)	4,5,6,7	None	18 day/900 km
Landsat-3	March 5, 1978	March 31, 1983	A,B,C,D (one-band side-by-side images)	4,5,6,7,8[a]	None	18 day/900 km
Landsat-4	July 16, 1982	—	None	1,2,3,4	1,2,3,4,5,6,7	16 day/705 km
Landsat-5	March 1, 1984	—	None	1,2,3,4	1,2,3,4,5,6,7	16 day/705 km
Landsat-6	October 5, 1993	Failure upon launch	None	None	1,2,3,4,5,6,7 plus panchromatic band (ETM)	16 day/705 km

[a]Band 8 (10.4–12.6 μm) failed shortly after launch.

The system was a pioneer in commercial RS, and most of the satellites dedicated to remote sensing today have essentially the same spectral bands. Today, LANDSAT uses two different sensors. The primary is the Thematic Mapper (TM), and the secondary is the Multi- Spectral Scanner (MSS). The TM has some advantages over the MSS,

because it performs on board analog-to-digital signal conversion over a quantization range of 256 digital numbers (8 bits). That represents an increment four times in the gray scale range with respect to the MSS, which has 64 digital numbers (6 bits).

Tables 6.7. Sensors Used on LANDSAT-1 to -6 Missions [Lillesand and Kiefer, 1994].

Sensor	Mission	Sensitivity (μm)	Resolution (m)
RBV	1,2	0.475–0.575	80
		0.580–0.680	80
		0.690–0.830	80
	3	0.505–0.750	30
MSS	1–5	0.5–0.6	79/82[a]
		0.6–0.7	79/82
		0.7–0.8	79/82
		0.8–1.1	79/82
	3	10.4–12.6[b]	240
TM	4.5	0.45–0.52	30
		0.52–0.60	30
		0.63–0.69	30
		0.76–0.90	30
		1.55–1.75	30
		10.4–12.5	120
		2.08–2.35	30
ETM[c]	6	Above TM bands plus 0.50–0.90	15

[a]79 m Landsat-1 to -3, and 82 m for Landsat-4 and -5.
[b]Failed shortly after launch (band 8 of Landsat-3).
[c]Landsat-6 launch failure.

Tables 6. 8. Thematic Mapper Spectral Bands [Lillesand and Kiefer, 1994].

Band	Wavelength (μm)	Nominal Spectral Location	Principal Applications
1	0.45–0.52	Blue	Designed for water body penetration, making it useful for coastal water mapping. Also useful for soil/vegetation discrimination, forest type mapping, and cultural feature identification.
2	0.52–0.60	Green	Designed to measure green reflectance peak of vegetation (Figure 1.10) for vegetation discrimination and vigor assessment. Also useful for cultural feature identification.
3	0.63–0.69	Red	Designed to sense in a chlorophyll absorption region (Figure 1.10) aiding in plant species differentiation. Also useful for cultural feature identification.
4	0.76–0.90	Near infrared	Useful for determining vegetation types, vigor, and biomass content, for delineating water bodies, and for soil moisture discrimination.
5	1.55–1.75	Mid-infrared	Indicative of vegetation moisture content and soil moisture. Also useful for differentiation of snow from clouds.
6[a]	10.4–12.5	Thermal infrared	Useful in vegetation stress analysis, soil moisture discrimination, and thermal mapping applications.
7[a]	2.08–2.35	Mid-infrared	Useful for discrimination of mineral and rock types. Also sensitive to vegetation moisture content.

[a]Bands 6 and 7 are out of wavelength sequence because band 7 was added to the TM late in the original system design process.

2. Resurs Series

Russia is now selling satellite imagery. The Resurs F is a military satellite series, which obtains information using a photographic camera (KFA 1000) that produces a five meter resolution panchromatic photograph. This satellite uses old technology and the information is obtained by recovering a film canister returned from orbit. The satellites normally have a life cycle of about one month. They have an almost circular orbit, with an altitude of 231 Km, 83° inclination, and period of 89 minutes. The Resurs-O are

digital earth resource satellites similar to LANDSAT. The satellite carries an MSS sensor in the wavelengths detailed in Table 6.9.

Table 6.9. RESURS-01 Characteristics [Deans, 1996].

SENSOR	BAND	1	2	3	4	5
MSU-SK	μm	..5-.6	.6-.7	.7-.8	.8-1.10	10.4-12.6
	Resolution (meters)	170	170	170	170	600
MSU-E	μm	.5-.6	.6-.7	.8-.9		
	Resolution (meters)	45	45	45		

The data can be purchased through EURIMAGE, a corporation that has an exclusive agreement with the Russian operators of the satellites.

3. Almaz

The Soviet Almaz 1A was launched in March 1991. It carried a Synthetic Aperture Radar (SAR) with a resolution of fifteen meters, which could image geologic formations regardless of cloud cover. It was the first commercial radar satellite. Data from the satellite was transmitted to a ground station in Moscow for storage on magnetic tapes, which were then provided to the customers. Almaz Corporation, an American subsidiary of Space Commerce Corporation, is the worldwide marketing agent for Almaz data. Due to higher than normal solar activity, the Almaz satellite's orbit was degraded rapidly. The satellite was destroyed when it reentered the earth's atmosphere in October,

1992. Although Russia has announced that it intends to place another Almaz satellite into orbit, though no date was confirmed. [US Army Space Reference Text, 1993]

4. SPOT

The program started in 1978, and SPOT-1 was launched in 1986, using an Ariane vehicle. The orbit of the first three SPOT satellites was exactly the same: circular near polar sun synchronous with a 98.7° inclination. It crosses the equator at 10:30 AM local time on the north- south passage. Although the pattern is repeated every twenty-six days, it has the advantage that the sensor can be reoriented, allowing the satellite to reimage selected ground areas within 1 to 4 days. The sensors on SPOT are two High Resolution Visible (HRV) imaging systems aided by magnetic tape recorders. Both of the HRV's produce panchromatic ten meter resolution imagery and multispectral color infrared twenty meter resolution imagery. The company is looking forward to the launch of SPOT 4 in the near future and the reactivation of SPOT 1, because the total system capacity has been reduced due to a SPOT 3 failure.

5. Dong Fang Hong Series

Another country having remote sensing capability is China. The FSW-2 and -3 series, Fanhui Shi Weixing or "Dong Fang Hong" (DFH) uses recoverable film canisters. DFH 43 was launched in October 1996, and its orbit decayed on November 4, 1996. Though it has not been advertised, experts speculate that the resolution is better than eighty meters. China also has a LANDSAT ground station. The perigee altitude was 172

Km, apogee altitude 335 Km, inclination 63° and period 89.5 minutes. The launch vehicle was a Long March 2D. [Lee, James G., 1994]

6. Japanese Earth Remote Sensing Satellite (JERS-1)

JERS-1 was launched in February 1992. It is in a sun synchronous orbit, with an altitude of 570 Km, 98° inclination, 96 minutes period and revisit period 44 days. It crosses the Equator on the descending node at 10:30 to 11: 00 AM local time.

It has optical sensors (OPS) and Synthetic Aperture Radar (SAR), both with eighteen meter resolution and a swath width of 75 Km. OPS can observe in seven spectral bands (visible to IR) and has stereoscopic capability. The launch vehicle was H-I (2-stage). The satellite had some problems deploying its SAR antenna after launch, but these were subsequently solved [Satellites & Sensors, 1997]. The data is not available commercially yet, but it will possibly be available in the future. Although Japan has developed launch vehicle capabilities in the past, Japan agreed not to sell them commercially to other nations in exchange for rocket technology received from U.S. NASDA's newest space launcher, H-II, is entirely a Japanese design, so Japan will be free to market it internationally. The H-II will have the capability to put 9,080 Kg in LEO and 3,600 in GEO. [Lee, James G., 1994]

The applications of this satellite cover the areas of agriculture, fishery, forestry, disaster protection, coastal monitoring and environmental monitoring The sensor characteristics are showed in Table 6.10.

Table 6.10. JERS-1 Characteristics [Deans, 1996].

SENSOR	BAND	1	2	3	4
OPS	μm	.55-.60	.63-.69	.76-.86	.76-.86
	GSD[6] (meters)	18.3x24.2	18.3x24.2	18.3x24.2	18.3x24.2
SAR	Spectral Band	Frequency	Polarization	Incidence Angle	Spatial Resolution
	C	1.275 Ghz	HH	35.21	18 m

7. Indian Resources Satellite Series (IRS-1A /1B/1C/P2)

India launched its first satellite in 1988 and now has four fully operational RS satellites. It is offering the product to the market at competitive prices. One of these products is multispectral imagery obtained through IRS-1A/B, with 904 Km altitude, 99.49° inclination, near polar sun synchronous orbit, period 103.2 minutes and repeating coverage every 22 days. The equatorial crossing is at 10.26 AM at the descending node. They all have Linear Imaging Self-Scanning sensors (LISS). LISS-I has 72.5 m resolution, 148 Km swath width, and LISS-II has 36.25m resolution, 74 Km swath width. Both have 4 spectral bands (visual to Near Infrared). [Avery and Berlin, 1992]

Another imagery product is obtained from the IRS-1C with 817 Km altitude, 98.69° inclination, near polar sun synchronous orbit, period 101.5 minutes and repeating coverage every 24 days. The equatorial crossing is at 10.30 AM at descending node. The sensors are LISS-III (multispectral), Panchromatic (PAN) and Wide Field sensor (WIFS) with a swath width 117.5 Km. The last satellite is the IRS-P2 with same orbital parameters but different sensor, LISS-II [INTERFACE, 1994].

[6] GSD stands for Ground Sample Distance. Basically the area covered by one pixel.

8. European Remote Sensing Satellite ERS-1 /2

The European Remote Sensing Satellite ERS-1 was launched in 1991 to a sun-synchronous near-polar orbit, altitude of 777 km, inclination 98.5°, period 100.5 minutes and recurrent periods of 3 days, 35 days or 176 days, depending on the operating mode [ERS-1 Data Book, 1991].

The ERS-2 was launched on 1995, in a similar sun-synchronous near-polar as ERS-1, altitude of 785 km and inclination 98.5°. Both satellites are almost identical.

The satellite payload has the following instruments:

-Active Microwave Instrument (AMI) which consists of two separate radars, a Synthetic Aperture Radar and a Wind Scatterometer. These enable three modes of operation: Image Mode, Wave Mode and Wind Mode.

-Radar Altimeter.

-Along Track Scanning Radiometer (ATSR).

-Precise Range and Range-rate Equipment (PRARE).

-Laser Retroreflector.

-Global Ozone Monitoring Experiment (GOME); on ERS-2 only.

The capability of the ERS includes the observation of atmospheric and surface properties (direction of the wave motion, surface wind vector, sea surface elevation, sea-surface temperature, monitoring of dynamic coastal processes, and detection of land usage changes) independently of time or weather [MWF products, USER Manual, 1991] [ERS-1 User Handbook, 1991].

9. CANADIAN RADARSAT

The first Radarsat was launched in 1995. The Radarsat project is led by the Canadian Space Agency and the product is available to the rest of the world through Radarsat International Inc. (RSI), a private corporation for commercialization. Placed into a circular sun synchronous orbit, altitude 98 Km, inclination 98.6 °, period 100.7 minutes and repeating cycle every 24 days, Radarsat provides global coverage every 4.5 days. The main feature of the Synthetic Aperture Radar (SAR) sensor is the capability to select different operational modes that provides resolutions from 10 to 100 meters and swath width from 50 to 500 Km. Table 6.11 gives an overview of the combination of operational modes.

Table 6.11. RADARSAT, Canada [Deans, 1996].

Sensor	Spectral band	Frequency	Polarization	Incidence Angle	Spatial Resolution	Swath Width
Overall	C[7]	5.3 Ghz	HH[8]	20-60	10x100 m	50-500 km
Standard				20-49	25x28 m	100 km
Wide				20-40	25x32 m	159 km
Fine				37-49	10x10 m	50 km
Scansar				20-40	50x50 m	300 km
					100x100 m	500 km
Experiment				49-59	25x25 m	75 km

[7] C band is a dominant frequency band for commercial satellites that extends from 4 to 6 Ghz.

[8] HH stands for horizontal polarization. Radar signals can be transmitted and received in different modes of polarization. In this case, horizontal when sent and horizontal when received. Since various objects modify the polarization of the energy they reflect to varying degrees, the mode of signal polarization influences how the objects look on the resulting imagery [Lillesand and Kiefer, 1994].

Designed to fulfill Canadian requirements, it is the most advanced SAR in orbit. Canada is covered by clouds most of time, so the cloud penetration capability of the SAR plays a key role allowing all weather imaging capability. The system is used for ice and ship detection, disaster monitoring, geological exploration, Arctic surveillance, Antarctic ice mapping and environmental monitoring.

VII. SPOT IMAGERY

A. INTRODUCTION

Imagery obtained from SPOT satellites has been, along with LANDSAT imagery, one of the most used around the world during the last decade. SPOT Imagery demonstrated not only excellent capabilities for commercial purposes but also for military ones. The introduction of remotely sensed imagery having panchromatic (PAN) ten meter resolution and color infrared having twenty meter resolution into the international market was a revolutionary action in such a politically sensitive industry as remote sensing.

Although used before by the military (for example to gather intelligence about Soviet laser facilities at Sary Shagan [Lee, 1994]), it was during the Persian Gulf War when SPOT military capability was certainly demonstrated.

The objective of this chapter, using SPOT imagery as an example, is to show how the Argentine Navy could take advantage of the available commercial remotely sensed imagery.

B. BACKGROUND

The SPOT satellite Earth Observation System was designed by the Centre National d'Etudes Spatiales(CNES), France, and developed with the participation of the governments of Sweden and Belgium as well as the private participation of several European banks and corporations. The SPOT system consists of a series of spacecraft and ground facilities for satellite control and programming, image production and

distribution.

SPOT satellites have been operational since 1986. The first satellite, SPOT 1, was launched on February 22, 1986, and was withdrawn from active service on December 31, 1990. The second, SPOT 2, was launched on January 22, 1990, and SPOT 3 on September 26, 1993. The SPOT 3 ended its service on November 14, 1996, due to an attitude control failure. SPOT 3 will be followed by SPOT 4, which is scheduled for launching in late 1997. Engineering for SPOT 5 has begun so that the satellite can be launched in 2001 to ensure service continuity.

SPOT provides commercial remote sensing products worldwide through a global network of control centers, receiving stations, processing centers, and data distributors. The Centre National d'Etudes Spatiales (CNES) owns and operates the SPOT satellite system while worldwide commercial data distribution is conducted by private companies (SPOT IMAGE Corporation in the United States, SPOT IMAGE in France and SATIMAGE in Sweden). Aerospacio has represented SPOT IMAGE in Argentina since 1989.

The spatial resolution of ten meters has been the best offered commercially for years. As a consequence of the future availability of having better resolution by the year 2000 (two or three meters instead of the five meters expected for SPOT 5), SPOT IMAGE Corporation, which already has the commercial structure for selling imagery worldwide, is positioning itself to become a reseller of other providers. For example, European Radar Satellite (ERS) imagery has already been commercialized in North America through SPOT IMAGE Corporation.

C. SYSTEM CHARACTERISTICS

1. Space segment

a. Orbital Parameters

The SPOT satellites fly in a circular, sun-synchronous orbit with the following parameters:

Altitude: 822 km

Inclination: 98.7 deg. (near-polar orbit)

Revolutions per day: 14.2

Period: 101.4 minutes

Westward drift between successive ground tracks: 2823 km

Cycle duration: 26 days

Orbital revolutions per cycle: 369

Based on these orbital parameters, the SPOT system provides global coverage between 87 degrees latitude north and south. The term "sun-synchronous" means that the satellite revisits a given place at the same time each day, so the conditions of illumination are the same from one visit to the next, allowing multitemporal comparisons.

b. Satellite

The payload on the SPOT series consists of two identical High-Resolution Visible (HRV) along-track scanners. The HRV instruments use closely packed one-dimensional linear detector arrays made of charged coupled devices (CCD's) that are

aligned perpendicular to the to the orbital track. There is one detector array for each spectral band.

Each HRV sensor operates in either black and white panchromatic, with ten meter resolution or multispectral mode, with twenty meter resolution. Table 7.1 shows the panchromatic and multispectral (MSS) bands used by the satellites SPOT 2 and SPOT 3.

Table 7.1. Spectral Regions used by SPOT satellites

SPOT 2/3				
SENSOR	BAND	1	2	3
MSS		.50-.59μm Green	.61-.68μm Red	.79-.89μm Near-IR
PAN		.51-.73μm		
MSS	Ground Resolution (meters)	20	20	20
PAN		10		

Each HRV sensor has an angular field of view of 4.13°, which produces a 60-km swath width for nadir viewing conditions. Based on that, the single pictures are formatted to cover a 60x60 Km ground area. Together, the HRV sensors view a 117-km area with 3-km overlap (Figure 7.1). HRV viewing angles can be adjusted by ground command up to 27° off nadir, increasing the viewing swath width to 950 Km (Figure 7.2). Using this capability of sensor orientation, a given location can be imaged many times within the standard revisit cycle of 26 days. This revisit time is also function of latitude. At the equator, the same point can be revisited seven times within a cycle, and a point located at 45 degrees of latitude can be revisited eleven times [Avery and Berlin, 1992].

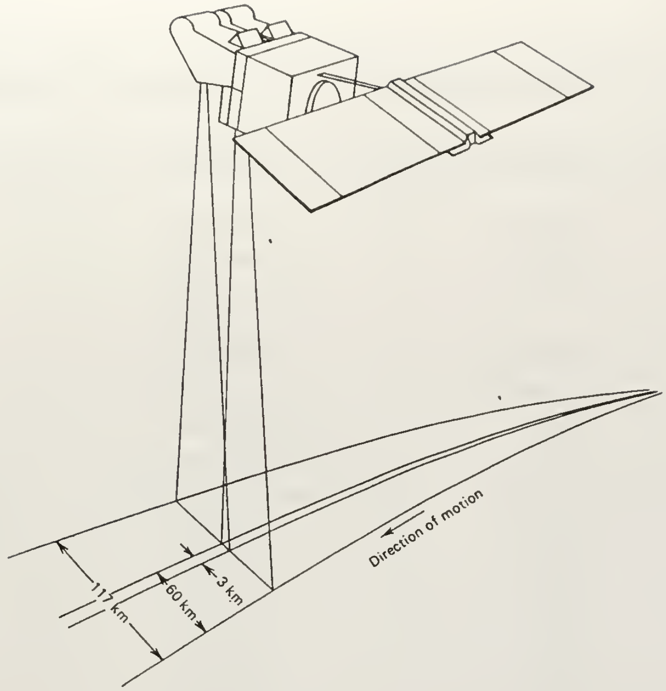


Figure 7.1. SPOT Ground Coverage with HRVs recording adjacent swaths [Lillesand and Kiefer, 1994].

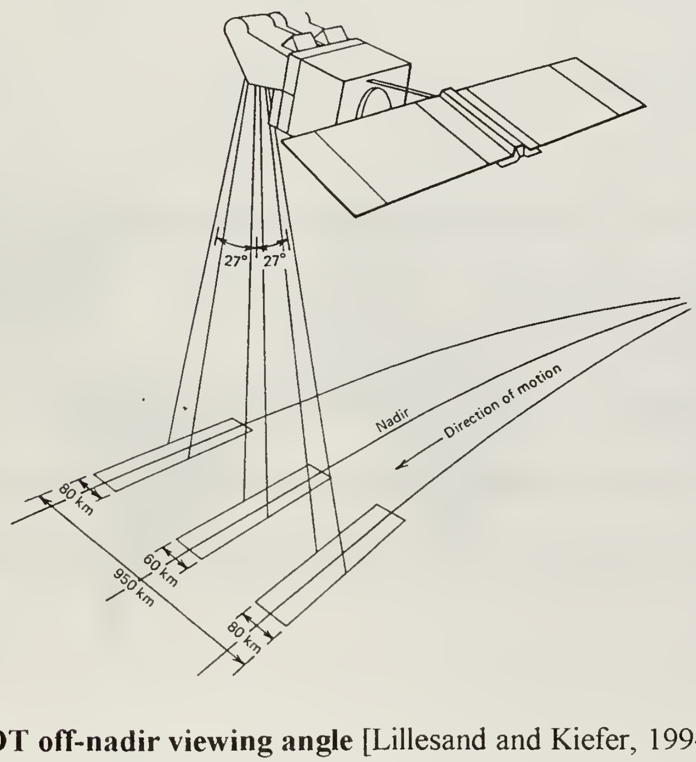


Figure 7.2. SPOT off-nadir viewing angle [Lillesand and Kiefer, 1994].

This off nadir viewing capability also provides stereoscopic image pairs of a given ground area (Figure 7.3).

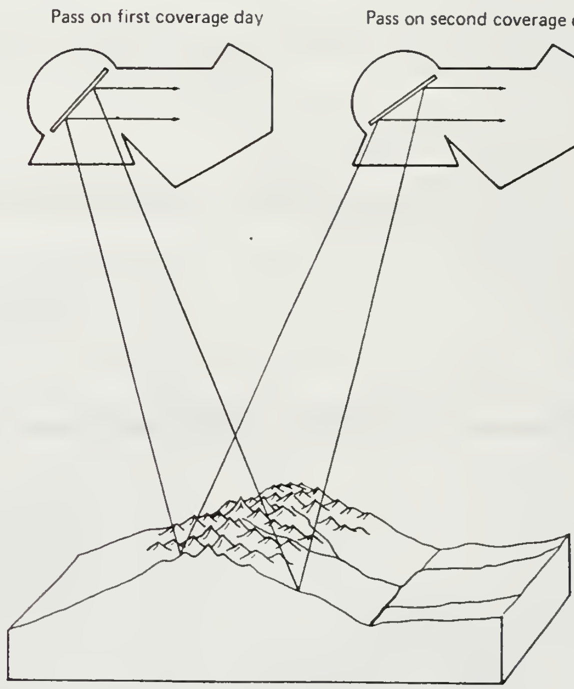


Figure 7.3. SPOT stereoscopic imaging capability [Lillesand and Kiefer, 1994].

2. Ground Segment

The ground segment is comprised of two main receiving stations, one in Toulouse, France, and the other in Kiruna, Sweden, and fourteen direct receiving stations. Table 7.2 and Figure 7.4 show the global ground station distribution and communication coverage.

Table 7.2. SPOT Receiving Stations [SPOT IMAGE, 1996].

Operator	Location	Commissioned
Canada	Gatineau	Jun-86
Canada	Prince Albert	Jun-86
Spain	Maspalomas (Canary Is.)	Nov-87
Brazil	Cuiaba	Apr-88
Thailand	Lad Krabang	May-88
Japan	Hatoyama	Oct-88
Pakistan	Islamabad	Jun-89
South Africa	Hartebeesthoek	Aug-89
Saudi Arabia	Riyadh	Oct-90
Australia	Alice Springs	May-90
Israel	Tel Aviv	Feb-91
Ecuador	Cotopaxi	Jul-92
Taiwan	Chung-Li	Jul-93
Indonesia	Parepare	Jul-93

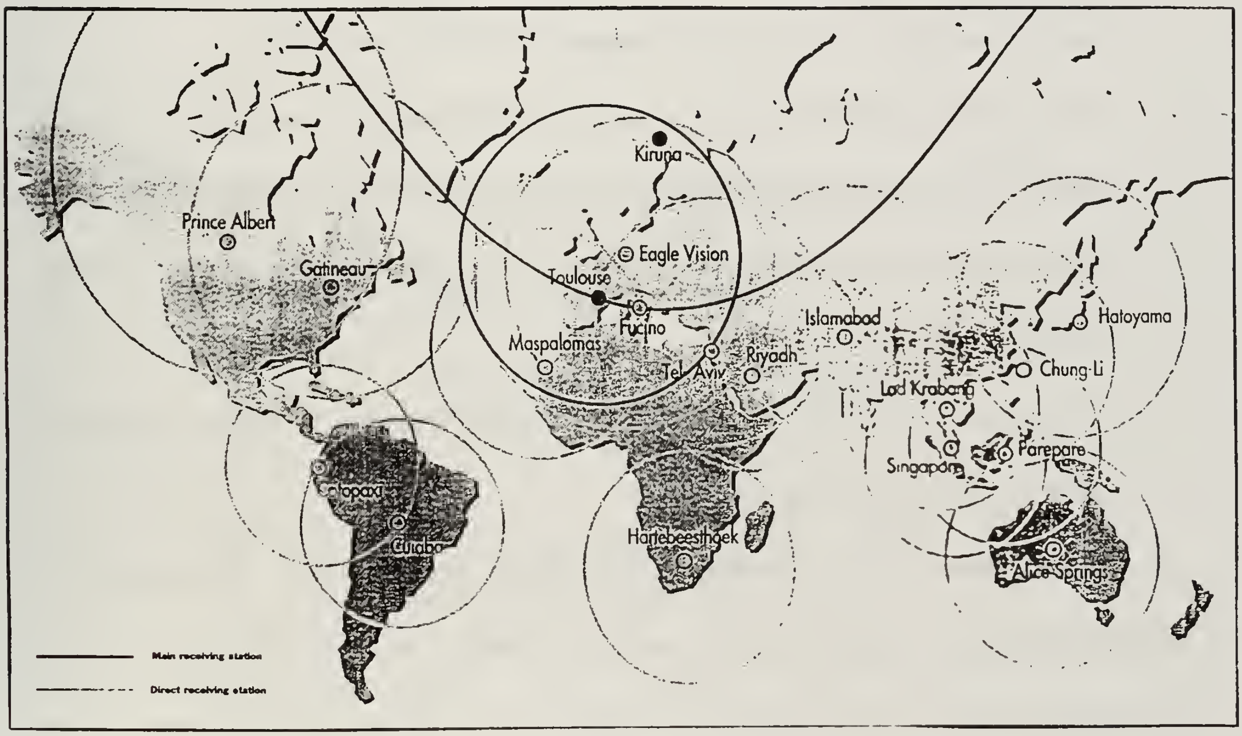


Figure 7.4. SPOT Receiving Stations [SPOT IMAGE, 1996]

D. OBTAINING DATA

SPOT data can be obtained in two different ways: real-time and recorded. Real time data is received when the satellite is in view of a receiving station and recorded data obtained when a satellite is not in view of any ground station. Image data can be stored on an on-board tape recorder and downlinked when in range of a ground receiving station.

Basically, four different situations can happen with respect to data acquisition:

- The satellite is within range of a Direct Receiving Station (DRS), so imagery can be down-linked in real-time, provided both satellite and DRS are suitably programmed.

- The satellite is not within range of a SPOT DRS. Programmed acquisitions are executed and the image data stored on the on-board recorders. The maximum storage capability is 22 minutes of imagery for SPOT 2 and SPOT 4.

- The satellite is within range of a main receiving station (Kiruna or Toulouse). It can thus be programmed either to down-link image data in real-time or play back the on-board recorders and transmit image data recorded earlier during the same orbital revolution.

- The rest of the time, the satellite is on standby ready to acquire imagery in accordance with uplinked commands.

Once obtained, data is processed and distributed commercially in accordance with particular agreements, depending on the nations and institutions. The normal time to get a desired image is about three weeks from the moment of submitting the initial request. The satellite provides raw data, which is then processed to make it understandable to the user.

Raw data can be used by those with the appropriate processing software, but this software is more expensive and complicated than the one developed to manage the elaborated data.[1] Many companies provide software that can manage the data. The products vary from raw digital data to elaborate pictures and mosaics of a given area.

Once the customer image requirement is established, SPOT IMAGE first checks to see if it can be satisfied with the data stored in the company data base. If the appropriate data is found, it is extracted and sent to the customer in the specified media (single picture, 4mm DAT cartridge tape, 8mm cartridge tape, 9-track magnetic tape, CD-ROM, or direct transfer through a network). If the required data is not found in the data base, the satellite is programmed to acquire it at the next available opportunity. The entire cycle is summarized in Figure 7.5.

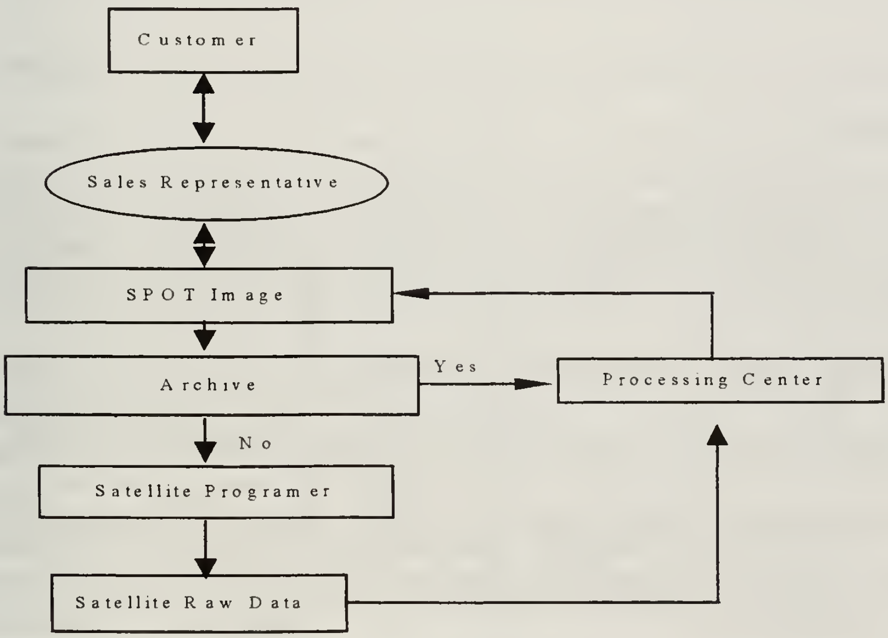


Figure 7. 5. Data request cycle

[1] The difference is that raw data needs more stages of process to make it useful. Elaborated products are ready to be used.

Data is presented in different product types useful for different purposes and continuously updated as the technology advances. Data products include:

- SPOT Scene™, has two different levels of processing: minimal processing, and radiometric and minimal geometric correction.
- Digital Elevation Models (DEM) represent terrain relief with x, y, z coordinates and are created from overlapping stereopairs of SPOT panchromatic or multispectral image data.
- SPOTView™ is rectified and corrected for use in Geographical Information Systems (GIS) and desktop mapping applications.
- MetroView™ is highly enhanced, off-the-shelf images of major U.S. cities for desktop mapping and business applications.
- LandClass™ provides land use classification with major land categories delineated.

Table 7.3 summarizes the SPOT products available in the international market during 1996 [Paige, 1996].

Table 7.3. SPOT Products

Product	SPOT Scene™		SPOT	SPOT	SPOT
Corrections	Level 1A	Level 1B	View™	Landclass™	Metro View™
Radiometric Corrections (Detector normalization)	Yes	Yes	Yes	Yes	Yes
Systematic Geo-correction			Yes	Yes	Yes
Map Projection			Yes	Yes	Yes
Geocoding			Yes	Yes	Yes
Orthocorrection			Yes	Yes	Yes
Format	LGSOWG[2]	LGSOWG	GIS-GeoSPOT	GIS-GeoSPOT	GIS-GeoSPOT
Application	Used by Image processing systems.		Mapping use	Different levels of land-use. Urban modeling	15x15 minutes Panchromatic image sets.

[2] LGSOWG stands for Landsat Ground Station Operating Working Group format

E. POSSIBLE ARGENTINE NAVY APPLICATIONS

Besides a number of civilian and government SPOT remote sensing applications, some of which are similar to duties assigned to the Argentine Navy (flood control and emergency preparedness, monitoring of coastal processes, and coastal mapping used in managing oil spill situations), there are specific military-proven applications for the system.

1. Mission Planing

Using Digital Elevation Models and the appropriate software, it is possible to have a mission planning system capable of providing accurate information about the terrain in a given region. Depending on the resolution of available imagery (in this case, I assume ten meters), it is possible to reconstruct a distant scenario and use it for planning and rehearsal. During the Persian Gulf War, coalition forces used SPOT data to build a variety of maps of the desert. Today, U.S. pilots are using SPOT data in three-dimensional flying simulators.[Pentecost, 1996] Although SPOT is not the only data used in these simulators, SPOT data played an important role in building the U.S. data base. In 1995, the U.S. Air Force publicly acknowledged using Virtual Reality Systems for planning and rehearsal of the operations in Bosnia. They used PowerScene™, a computer system which created a three-dimensional image of every square inch of Bosnia. PowerScene™ was manufactured by Cambridge Research Associates of McLean Virginia, and is commercially available. Although mainly conceived to help pilots, it also can be used in general mission planning [The Washington Post, 1995].

2. Military Analysis

Damage assessment of a given area can be done using imagery with ten meter resolution. For example, Figure 7.6, with pictures taken during the Desert Storm, shows how the southern bridge over the Tigris River, clearly visible in the first image (02-19-91), has been almost completely destroyed (image dated 03-19-91).

3. Surveillance

An appropriate interpretation of the changes observed in a given area from space-based sensors gives the intelligence analyst a worthy source of information. For example, an unusual increase of industrial activity in an isolated area could represent clandestine military activities. Although not infallible, remotely sensed imagery with ten meter resolution can be accurate enough for detecting changes in many cultural features (nuclear plants, ballistic missiles, ship construction, and new military bases).

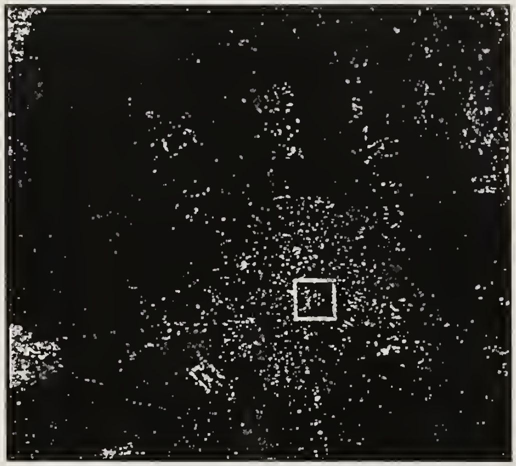
F. SPOT FEATURES

In addition to the generic benefits and disadvantages applicable to all commercial remotely sensed imagery, which I discussed in the preceding chapter, SPOT provides a few special features that should be considered at the time of making the decision of whether or not to purchase its data.

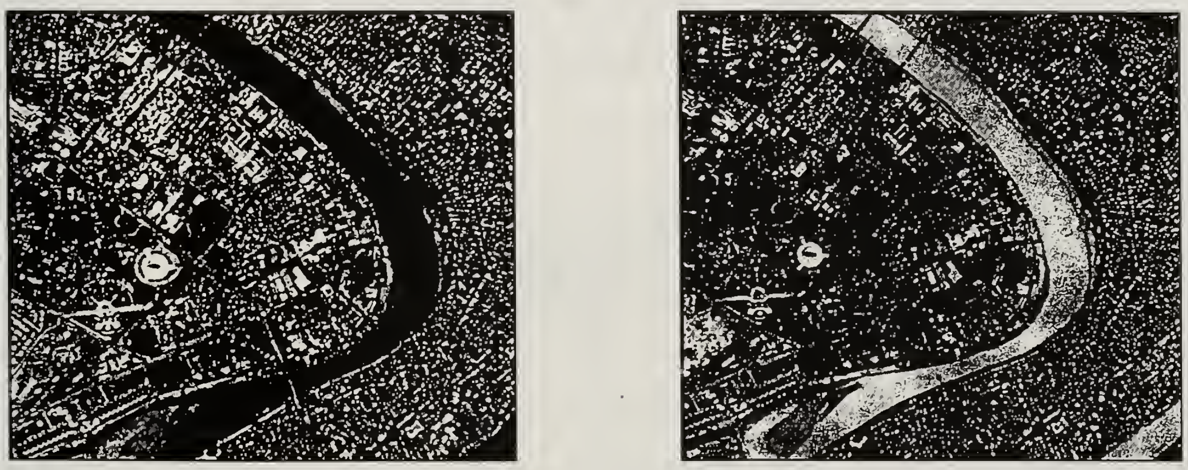
1. Standardized Products

Because SPOT IMAGE has been acquiring and selling imagery for more than ten years, the infrastructure is established and continuously improved. The data is presented

in standardized formats and the software required to understand and use it is also clearly defined.



Baghdad full scene (60 x 80 km) with area highlighted for enlargement



Bridges over the Tigris River, before (left - 19 February 1991) and after (10 March 1991) are seen in these 5 x 5 km subscenes. The southern bridge has been almost completely destroyed on the right image. One of upper bridges has a large section missing. The Revolutionary Palace complex is seen around the circular white structure to the left.

Figure 7.6. SPOT Picture 60x80 Km enlarged in a given area to 5x5 Km [SPOT Imagery, 1996].

2. Stored Data Available

SPOT imagery has a huge data base, which contains all the information obtained by SPOT satellites since the beginning of its operations. When the information is already in this data base, the time required for the customer to receive it is relatively minor, compared with information that must be acquired.

3. Sensor Tilt Capability

The sensor orientation capability, up to 27 degrees from nadir, allows much shorter revisit periods than any other existing commercial system.

4. Along Track Scanner

SPOT satellites were the first commercial imagery system to use an along-track scanner or "Push-Broom" technology.

The across-track scanner in Landsat, uses a rotating mirror, which scans the terrain along scan lines that are perpendicular to the line of flight (Figure 7.7).

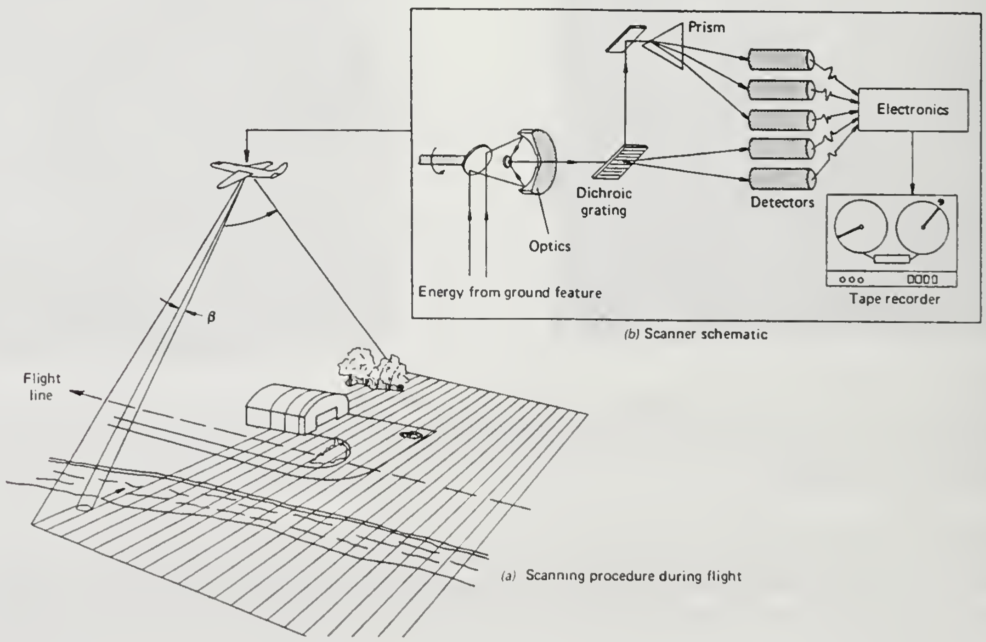


Figure 7.7. Across Track Scanner on an Aircraft Platform [Lillesand, 1994].

The along-track scanner (Figure 7.8) uses a linear array of detectors to scan in the direction perpendicular to the flight line. In this case, all the points along the same perpendicular line are scanned at the same time. From the technical point of view, the elimination of the rotating mirror (used by LANDSAT) reduces the risk of failure, and the satellite requires less power, has a longer life and has higher reliability. This configuration enables a much stronger signal to be recorded.

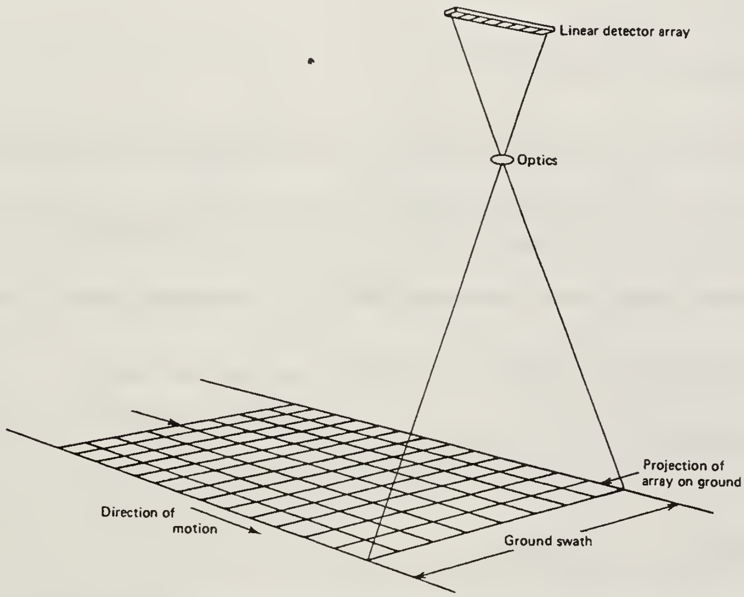


Figure 7.8. Along Track Scanner [Lillesand and Kiefer, 1994].

5. Cost

There is a complete list of prices provided by SPOT IMAGE Corporation (Table 7.4). It is interesting to note that the prices for U.S. are about 20 % less than for international customers. One of the possibilities suggested during a visit I made to the

SPOT IMAGE Corporation in Reston, Virginia, in 1996, was that the acquisition of imagery could be made through the U.S. National Imagery and Mapping Agency (NIMA). At first look, this procedure could be feasible, because there is an agreement established between the NIMA and Servicio de Hidrografia Naval of Argentina (SHN) concerning nautical cartography and geodesy. This agreement, clearly defines and contemplates the cooperation points and limitations. Though, I consider it outside of the scope of my study, I recommend that the legal aspects should be be considered before making a decision to purchase SPOT IMAGERY through this way.

6. French Ownership

This particular feature can be defined as an advantage from the point of view that we, the Argentine Navy, used to do business with the France (ships, airplanes and missiles). On the other hand, it is clear that SPOT is a company that will respond to its own interests in situations of military crisis, which means that will be very sensitive to pressures from the French and U.S. governments.

7. World-wide Availability

Almost every nation can get access to the same SPOT information, so it creates the risk that its resources can be used by potential adversaries.

Table 7.4. SPOT Product Prices During 1996 [SPOT IMAGE, 1996].

SPOT Scene - Level 1 Products

	P	XS
Standard Full Scene (37x37 mi.) Level 1A or 1B; Panchromatic or Multispectral Available in digital, print or film. U.S. only International	 $2,800 $3,400	 $1,950 $2,600
SPOT Album - Any full scene imagery 4 or more years old calculated from Jan 1 of the current year. (Level 1B CD-ROM only) U.S. only International	 $1,400 $1,700	 $975 $1,300

SPOTView®- Digital Ortho Imagery for GIS

	SPOTView BASIC (Digital Only)			SPOTView PLUS (Digital, Film or Print)		
	P	XS	P/XS Merge	P	XS	P/XS Merge
15 - (15 x 15 minute area) - U.S. only	$2,750	$2,200	$4,250	$3,650	$3,100	$5,400
15 - (15 x 15 minute area) - International	$3,150	$2,450	$4,800	$3,850	$3,200	$5,800
FS - Full scene (37 x 37 miles) - U.S. only	$3,950	$3,150	N/A	$4,900	$4,200	N/A
FS - Full scene (37 x 37 miles) - International	$5,700	$4,450		$6,500	$5,400	
30 - (30 x 30 minute area) - U.S. only	$6,750	$5,000	$11,000	$7,750	$6,000	$12,650
30 - (30 x 30 minute area) - International	$7,450	$5,500	$12,000	$8,250	$6,250	$13,500
NEW ➡ MetroView® - Enhanced imagery of major U.S. urban areas - available in 15 x 15 minute grids						$495 (digital only)
NEW ➡ Statewide 1000 - 30 x 30 minute grids (approx. 1000 square miles) of existing statewide databases						$1,500 (digital only)

Large Area/Volume Pricing

	U.S. (digital only)		International (digital only)	
	P	XS	P	XS
Area - Minimum 2500 sq. mi. with 20 mi. minimum side SPOT Scene (Prices per square mile) SPOTView (Prices per square mile)	 $3.90 $5.50	 $2.75 $4.40	 $4.75 $6.10	 $3.60 $4.80
Corridor - SPOTView minimum length 100 miles, 2.5 mi. wide (Prices per linear mile)	$70	$56	$85	$68
Statewide - Complete SPOTView coverage of any U.S. state (Prices per square mile)	$4.50	$3.60	N/A	
Price per participant for 10 or more participants per square mile	$.45	$.36		
Overlapping Coverage - For multiple scenes of the same area. Scene centers must be less than 18 km apart. Programming may be requested on one scene; all others from archive. Standard SPOT Scene or SPOTView products.	50% off list price for second and additional lower-priced scenes that overlap base scene. All scenes must be purchased on the same order. No other discounts apply.			

Archive Searching - Direct Client Access

WWW Access - Archive searches through the SPOT WWW site	Call for information
DALI - Software to search SPOT's worldwide archive to determine characteristics of available imagery and to preview sub-sampled digital quick-looks (500 x 500 pixels) of imagery. For use on Macintosh® or PowerPC® platform. Requires an Ethernet LAN with a network connection to the Internet.	$4,995 (one time fee)

VIII. SEA VIEWING WIDE FIELD OF VIEW SENSOR (SEAWIFS)

A. INTRODUCTION

The Sea-viewing Wide Field-of-view Sensor (SeaWifs) program is an improved version of the Coastal Zonal Color Scanner (CZCS), which flew on board the Nimbus 7 satellite from the fall of 1978 to the summer of 1986.

SeaWifs will allow mapping of ocean color of the entire oceans for a period of five years. Ocean color is function of the concentration of phytoplankton and other pigments in the water. The purpose of SeaWifs is to examine factors that affect global change. Because of the role of Phytoplankton in the global carbon cycle, data obtained from SeaWifs will be used to asses the ocean's role in the global carbon cycle as well as other biogeochemical cycles. SeaWifs data will be used to help elucidate the magnitude and variability of the annual cycle of primary production by marine phytoplankton and to determine the distribution and timing of spring blooms. SeaWifs data will also help to visualize the dynamics of the ocean and coastal currents, the physics of mixing, and the relationships between ocean physics and large-scale patterns of productivity.

SeaWifs is a part of the Earth Probes Initiative within the National Aeronautics and Space Administration (NASA), which directs its attention to satellites with short lead time and simple launch requirements. SeaWifs was successfully launched on a Pegasus XL vehicle on August 1, 1997 and reached its final orbit on September 3 [Ray, 1997]. SeaWifs is part of the SeaStar satellite, developed by Orbital Sciences Corporation (OSC). Orbital Sciences Corporation is a prime contractor, and the program represents for NASA

a new way of accomplishing its objectives. For the first time, NASA has contracted to purchase Earth Science research data from a private firm, OSC. NASA will furnish SeaWifs research data to scientists who file a formal data request and agree to specific terms and conditions. OSC will keep the right to commercialize SeaWifs data to the marine industry, other U.S. federal agencies and foreign governments.

The U.S. Navy is interested in using SeaWifs data to support Naval Operations. Ocean color information can contribute in the planning of operations such as deploying and detecting mines, deploying landing forces, submarine stationing, anti-submarine patrol and managing the fleet movements. [Hooker, 1992]

Figure 8.1 shows the SeaWifs program elements.

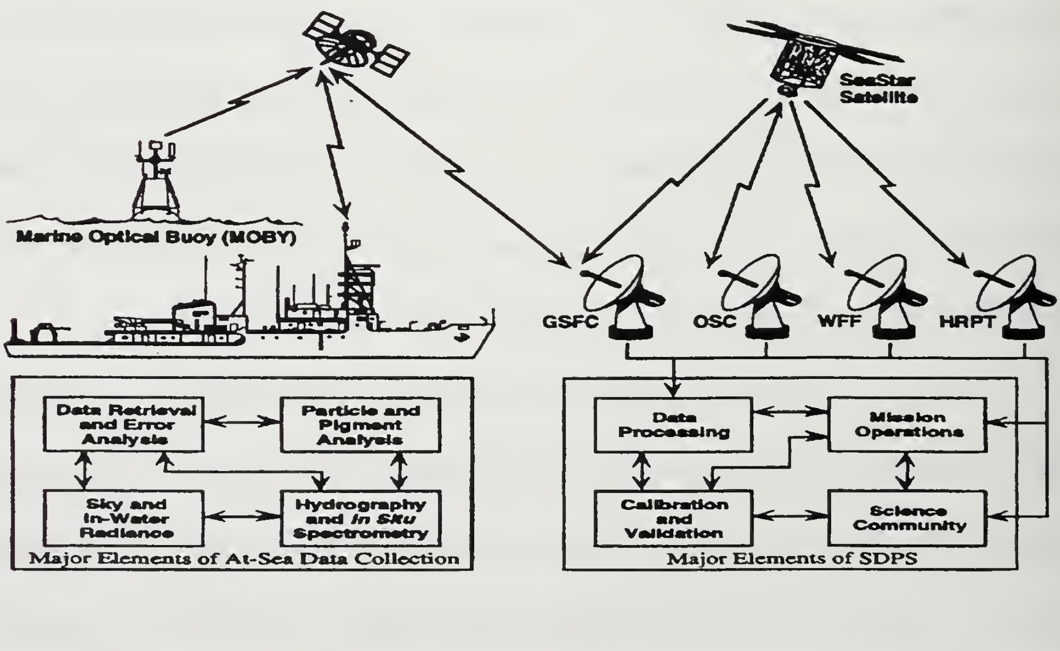


Figure 8.1. Major Elements of Shore and Sea Based Data Processing. [Hooker, 1992]

B. SYSTEM ARCHITECTURE

Unlike other satellite Systems, which are basically divided into space segments and ground segments, SeaWifs is managed in different way. Conceptually, the system is divided into two parts: The space segment, which includes satellite, sensor and the ground support system, and the SeaWifs Data Processing System.

1. Space Segment

a. Satellite

The SeaStar satellite, developed by OSC, was launched to a Low Earth Orbit on board an extended Pegasus XL launch vehicle. Figure 8.2 shows the launch sequence and Figure 8.3 the satellite itself.

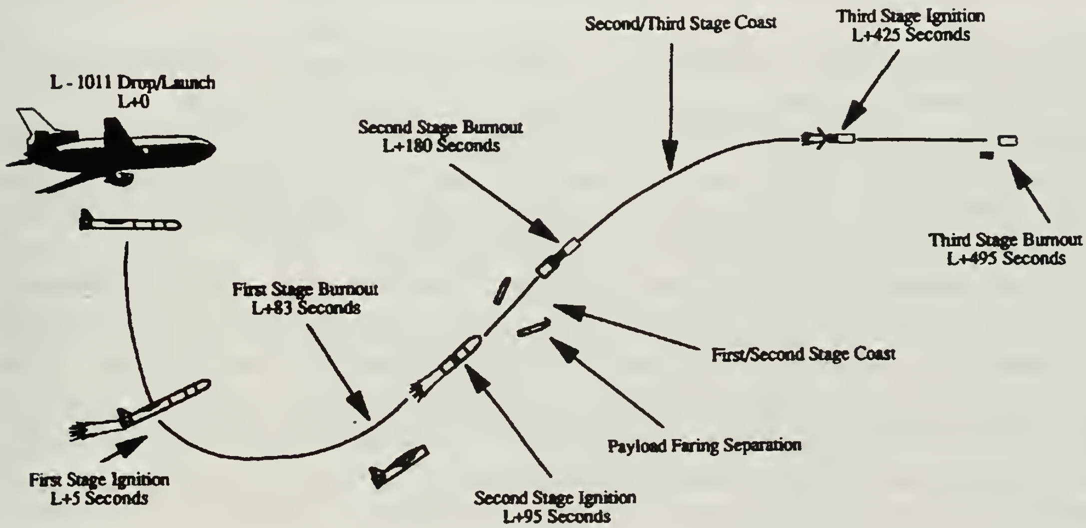


Figure 8.2. SeaStar Launch Sequence. [Hooker, 1992]

The Pegasus launch vehicle was flown aloft under the wing of specially modified Lockheed L-1011 aircraft and released at an altitude of about 39,000 ft. From here the launch vehicle brought the spacecraft to a LEO, circular, parking orbit of 278 Km. altitude and inclination 98.20 °. The solar panels were then deployed assuring, along with Nickel Hydride (NH_2) batteries, the provision of the required power.

The SeaStar has an onboard hydrazine propulsion system that was used to raise the satellite to its final orbit and will be used to make appropriate corrections when needed over the entire mission life. The final orbit was established at 705 Km altitude, circular, sun-synchronous, crossing the equator at noon (descending). The period is about 90 minutes, and the inclination of 98.20 ° assures worldwide coverage, including higher latitudes.

The attitude control system (ACS) will provide the required technical elements to maintain the altitude, performing lunar and solar calibration maneuvers and providing attitude knowledge within one SeaWifs pixel. The ACS is three-axis stabilized comprised or orthogonal magnetic torque rods for roll and yaw control and two momentum wheels for pitch stabilization. The information from the satellite is downlinked through two different data streams. The first is real-time, Local Area Coverage (LAC), transmitting data merged with spacecraft health and instrument telemetry at 665.4 Kbps. The frequency is 1702.56 Mhz (L-Band). The second is stored, Global Area Coverage (GAC) and selected LAC, along with spacecraft health and instrument telemetry, at 2.0 Mbps. The frequency is 2272.5 Mhz (S-Band). The command system uses an uplink frequency of 2092.59 Mhz (S-Band).

The orbit determination is achieved by redundant global positioning system (GPS) receivers on board the satellite. The orbit state is included in the spacecraft health telemetry.

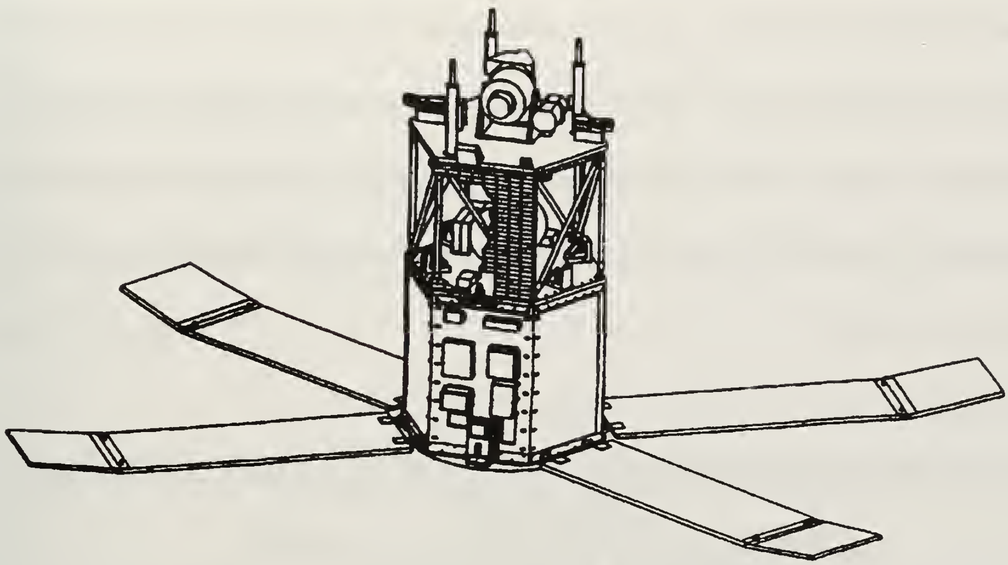


Figure 8.3. SeaStar Satellite with solar panels deployed.[Hooker, 1992]

b. Sensor

Built by Huges /SBRC, the SeaWifs instrument is the centerpiece of the entire program. SeaWifs takes advantage of the experience gained during operation of the CZCS operations. The SeaWifs instrument consists of an optical scanner and an electronic module. The optical scanner collects incoming radiation from the scene through the folded telescope. The radiation is then reflected onto the rotating half-angle mirror. Then, the radiation is separated into four wavelength intervals (each one containing two of the band wavelengths) and finally passed through band pass filters to separate it into the eight required SeaWifs spectral bands.

The detected radiation signals are then amplified by preamplifiers for Time Delay and Integration (TDI) processing in the electronics module. Inside the electronic module the signals are amplified and filtered to limit the noise bandwidth. Then the filtered signals are digitized and directed to a commandable processor where the TDI operation is performed in real-time as data is generated. The resultant signals are encoded to 10 bit numbers and then sent from the processor to the spacecraft data system at 1,885 Mbps during the data acquisition period. Table 8.4 shows the major characteristics of the SeaWifs ocean color sensor.

Table 8.1. Major Instrument Parameters and Characteristics [Hooker, 1992]

Instrument Bands				
Band	Wavelength FWHM [nm]	Saturation Radiance[1]	Input Radiance[1]	SNR[2]
1	402–422	13.63	9.10	499
2	433–453	13.25	8.41	674
3	480–500	10.50	6.56	667
4	500–520	9.08	5.64	640
5	545–565	7.44	4.57	596
6	660–680	4.20	2.46	442
7	745–785	3.00	1.61	455
8	845–885	2.13	1.09	467

Sensor Accuracy	
Radiance Accuracy:	<5% absolute each band
Relative Precision:	<1% linearity
Between Band Precision:	<5% relative band-to-band (over 0.5–0.9 full scale)
Polarization:	<2% sensitivity (all angles)
Nadir Resolution:	1.1 km LAC; 4.5 km GAC
Mission Characteristics	
Orbit Type:	Sun Synchronous at 705 km
Equator Crossing:	Noon ±20 min., descending
Saturation Recovery:	<10 samples
MTF[3]:	≥0.3 at Nyquist
Swath Width (at equator):	2,801 km LAC (±58.3°) 1,502 km GAC (±45.0°)
Scan Plane Tilt:	+20°, 0°, −20°
Digitization:	10 bits

1. Units of $\mathrm{mW\,cm^{-2}\,\mu m^{-1}\,sr^{-1}}$.
2. Minimum values measured at input radiances.
3. Modulation Transfer Function.

c. Ground Support System

The ground segment serves three functions: spacecraft control, data delivery to NASA Goddard Space Flight Center (GSFC), and data delivery to commercial users. The first and third functions are the sole responsibility of OSC, the second is supported by different stations. The stations involved in the SeaStar Ground Support System are: Spacecraft Operation Center (SOC), GSFC High Resolution Picture Transmission (HRPT), NASA Wallops Flight Facility (WFF) HRPT, and NASA-approved HRPT facilities.

(1) Spacecraft Operation Center. The SeaStar Spacecraft Operation Center (SOC) is an OSC facility located in the Washington, DC area. The SOC has a fully steerable five meter antenna, PC-based tracking computer, and redundant receivers and demodulators for both the 2.0 Mbps S-Band GAC and LAC stored data transmission, and 665 Kbps L-Band direct broadcast HRPT LAC telemetry data stream. Redundant telemetry/command consoles provide telemetry processing and command capability. The SOC also contains commercial science data processing and product generation facilities. Although OSC will operate the SOC, the SeaWifs Project Office (SPO) at NASA will define recording times, sensor tilt angle, recorded data transmission times and calibration events, within limits of safe operation, and it will forward these parameters to the SOC. The SOC will be manned during the noon pass but it will function automatically during the midnight pass.

(2) NASA Goddard Space Flight Center High Resolution Picture Transmission. The ground station located at GSFC has a mission to acquire the direct

broadcast data. This HRPT ground station consists of a prime computer system with two backup systems. The primary antenna is an eight foot perforated parabolic antenna dedicated to the capture of SeaWifs HRPT data. The backup antenna is the one used for the search and rescue satellite (SARSAT), and it will be available to SeaWifs when it is not needed for SARSAT.

(3) NASA Wallops Flight Facility High Resolution Picture Transmission. Wallops Flight Facility HRPT is designed for the acquisition of the recorded data. The primary antenna is a nine meter autotrack. The backup antenna is a 7.5 meters receive-only autotrack that is available on a non-interference basis with the Wallops launch range. The recorded data will be transmitted to the SeaWifs Data Processing System (SDPS) at GSFC where the data will be stored in a computer addressable file on disk.

(4) NASA Approved High Resolution Picture Transmission. Approved HRPT are all the stations authorized by NASA to receive LAC data. These HRPT stations will collect the 1.13 Km resolution data over surrounding areas.

2. SeaWifs Data Processing System

The major elements of SeaWifs Data Processing System are:

a. Data Processing

This element receives raw science data and generates the global ocean color data products, which will be provided to the GSFC Distributed Active Archive Center (DAAC) for archiving and distribution.

b. Calibration and Validation

This element is responsible for data quality analysis of SeaWifs products. It generates analysis reports and is responsible for establishing and updating calibration procedures for SeaWifs data. Its main goal is to determine the degree to which the commercially procured ocean color data fulfills the contractually stated NASA requirements.

c. Software Support

This element is responsible for programming assistance and data base support, software updates, software integration, software testing and software configuration management.

d. Mission Operations

This element serves as the single point-of-contact for OSC and the GSFC HRPT station to communicate, coordinate, schedule, and report any problems.

In summary, the authorized HRPT's get the data and store it in order to satisfy requirements.. Requirements can be originated by authorized researchers to whom the information is sent in accordance with a NASA agreement or commercial users to whom the data is sent in accordance with OSC commercial agreements. Eventually, researchers can get operational data by asking special permission of NASA.

C. SEAWIFS DATA MANAGEMENT

The type of mission SeaWifs was developed for (monitoring the color of the entire ocean) along with the research-commercial combination established between NASA and

OSC, makes the management of data one of the most important issues. The sensor and mission operations are designed to meet NASA research requirements. In order to satisfy OSC commercial requirements, there is a general embargo period of two weeks for distribution of research data by NASA and five years before the data is transferred to the public domain. However, there are three exceptions to the embargo period:

- Field experiments requiring data for ship positioning
- Instrument calibration and validation activities
- Demonstrations to prove feasibility for operational use.

The interesting point for scientists is that access throughout NASA will be permitted for research purposes. To get this access, scientists must establish a project and obtain NASA's permission. Once they get NASA's approval, they must sign an agreement stating that the data will be used only for research purposes. The data is provided by NASA at basically no cost through the internet or at the minimum cost through other media (CD room, magnetic tape, etc.).

SeaWifs produces two types of science data, LAC with a ground resolution of 1.13 Km and GAC data with a resolution of 4.5 Km. Direct broadcast LAC will be received by all the real-time Ground Stations (NASA-approved HRPT) around the world. Recorded LAC data for pre-selected areas and all GAC data will be received at the WFF and forwarded to the SDPS at GFSC. SDPS will receive data, manage it, catalog it, archive it, generate products, ensure distribution, schedule missions, support software updates and provide technical training.

Figure 8.4 illustrates the anticipated distribution and coverage once the system is operational.

Figure 8.4. Expected distribution of the world NASA approved HRPT

Summarizing, OSC is responsible for commercializing the product for operative or commercial purposes. Operative use means the use of data in real-time, which is very important in fishery and fleet management. The data is no longer considered operative after two weeks, and it is then released by NASA to the authorized researchers at virtually no cost. Figure 8.5 provides an overview of how SeaWifs data is obtained and distributed.

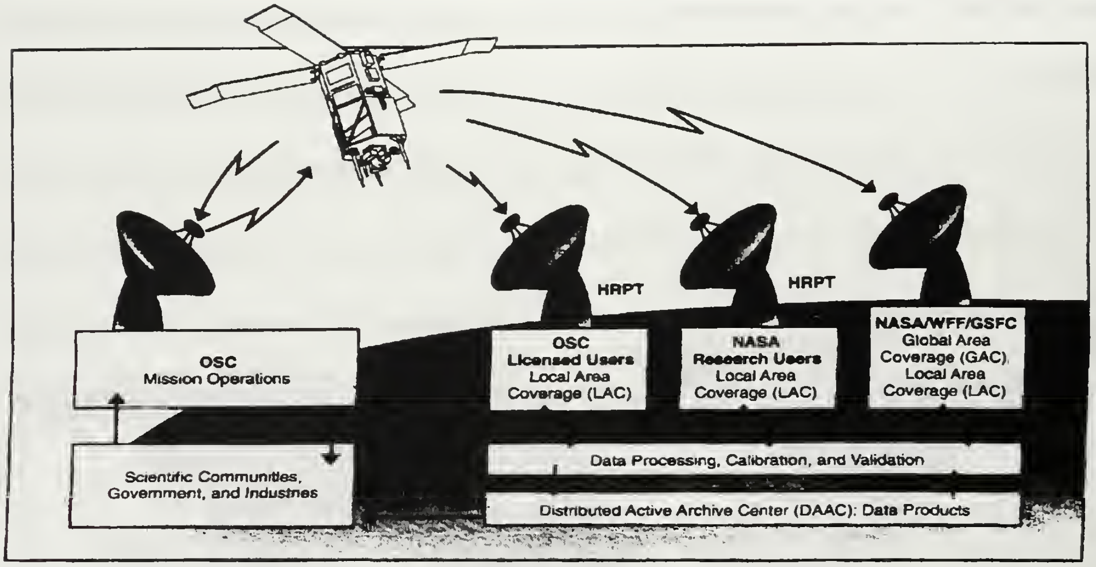


Figure 8. 5. SeaWifs data flow and distribution scheme

D. SEAWIFS APPLICATIONS

NASA's purpose in supporting the SeaWifs project is to obtain valid ocean color data of the world's oceans for a five year period, to process that data in conjunction with ancillary data about meaningful biological parameters, and to make that data readily available to researchers. OSC's intent is to make SeaWifs a profitable activity based on commercial applications. These complementary interests formed the basis of the NASA-OSC agreement.

1. Research Applications

Obtaining frequent measurements over vast expanses of oceans is extremely using conventional oceanographic data collection procedures. Large areas can not be covered by the same ship at the same time. For example, small-scale features (about 30 km), change faster than research vessels can map them. Larger scale features are even more

difficult to map. SeaWifs can get more data in one orbit than one ship can get in ten years, and this argument is powerful enough to consider its use. Of course, the spatial resolution, spectral resolution and delivery time restrictions inherent in current satellite systems place some limits on measurements that can be made. Also, satellite sensors have the obvious disadvantage of not being in physical contact with the ocean. However, in the 1960's, measurements from aircraft and ships proved that ocean color measurements from satellite-based sensors provide a powerful tool for understanding oceanic biological and physical processes.

The satellite sensors used for ocean color measurement measure the spectrum of sunlight reflected from the ocean's waters. The radiance reflected from the ocean in the visible wavelength region (0.4-0.7μm) depends on the concentration of chlorophyll, sediments and dissolved materials from terrestrial and inland sources. The open waters usually appear deep blue, because they contain very little phytoplankton or other substances. When we move toward shore, nutrients increase and the water turns green as the chlorophyll increases(chlorophyll has a pigment that reflect green light and absorbs other colors). Hence, the concentration of phytoplankton can be estimated from the measure of chlorophyll concentration. With the presence of sediments and dissolved materials, the color approaches yellow-brown and sometimes red These suspended substances generate what is known as turbidity, or decreased water clarity, which represents an important parameter for military applications.

Using appropriate algorithms, the amount of chlorophyll and other pigments can be determined and hence the ocean characteristics established during different seasons.

Many scientific contributions can be obtained from the analysis of chlorophyll concentration and seasonal displacements (for example, the relation between pigments and primary productivity and pigments and El Niño Southern Oscillation).

2. Commercial Applications

Data provided on ocean color is very useful for the fishing industry. Phytoplankton is the principal source of organic matter that sustains the marine chain food. Normally the fish population is located where the nutrients are, so having accurate nutrient information improves catch efficiency. SeaWifs data will also be useful in determining ocean organic pollution, fronts, eddies and ocean current features. This information could be useful for marine transportation, offshore oil and gas exploration and extraction, ocean mining and value added products such as fishery aids charts.

3. Operational Applications

The National Oceanic and Atmospheric Administration (NOAA), identified the following as potential operational uses of SeaWifs data: Ocean dumping monitoring, noxious algae blooms and red tides, regional characterization, habitat assessment, flow visualization, and oil spill trajectory analysis. SeaWifs data can also support naval operations in much the same way that it supports fleet management. One example is the identification of current boundaries, as in the case of a Loop Current in the summer: [Hooker, 1992]

> *The observed ocean color signals integrates over the upper few to tens of meters of the water column. This allows for slight differences in the bio-*

optical characteristics in underlying waters of the loop current and coastal waters to be readily distinguishable from each other with satellite color observations at times when the upper centimeters of surface waters are thermally homogeneous.

E. POSSIBLE USES OF SEAWIFS DATA BY THE ARGENTINE NAVY

The SeaWifs data will be available on a commercial basis through OSC once the system established and declared operational. Before acquiring data, the Argentine Navy should study and define how this data can be used to satisfy operational requirements or to support naval operations.

One way to make appropriate use of the SeaWifs data obtained in real-time is by having an adequate and proven algorithm that could relate local meteorological patterns to the local ocean color observations. Scientists are developing such algorithms all over the world with different objectives. For example, one of the most general and ambitious projects is the SeaWifs Study of Climate, Ocean Productivity, and Environmental Change. This propose project attempts to use SeaWifs data to address:

-The role and significance of oceanic biological processes in climate control.

-The ecological and environmental change at the land sea boundary.

-The diffuse attenuation coefficients, mixed layer depths, ocean physical processes, bio-optical signatures as tracers of water motions, spatial heterogeneity, upwelling and frontal dynamics.

- the role of biology in models of the climate system., which include ocean atmosphere interactions.

This project, used as an example to show how broad SeaWifs data can be used, involves the cooperation of different centers (Ocean Marine Exchange (OMEX), Natural Environment Research Council (NERC), British Antarctic Survey (BAS), and others). The final objective is to link *in situ* measurements,[1] algorithm development, image validation, and exploitation of SeaWifs data. [Hooker, 1993]

It is very important to note that all these projects are quite demanding in terms of effort, *in situ* data collection, and ocean measurements, which could take years to obtain and verify. Projects like this are surely justified as long term scientific endeavors but not from the military point of view, if we expect to immediately and entirely satisfy our local requirements.

Which Argentine Navy needs could ocean color data satisfy? In the long term, the seasonal study of the ocean color patterns can help us make better decisions when planing naval operations, in particular:

1. Fishing Control

Knowing where the phytoplankton is, we can increase our surveillance of specific areas based on the presumption that illegal fishing ships will be around those areas. Knowing where to send our aircraft patrols or our ships can save us considerably time and money. There are other more accurate methods of determining where and when

[1] In situ means that the measurement is made with the device in contact with the object being studied, as opposed to a remote measurement of reflected or emitted electromagnetic energy

unauthorized ships are operating (for example, Radarsat). However, if we don't have Radarsat ocean color data used for seasonal prediction can be a good tool for planning.

2. Mining Operations

Ocean color measurement provides an indication of not only the chlorophyll concentration but other pigments as well. Turbidity of the water can play a key role in defining the best place to establish a particular type of mine field. For example, if I know the depth at which a submerged object can be seen from the air I can use this to my advantage. In the case of defensive mine field, I can collect enough information without needing a ocean color data, but when planning an offensive mine field, color data could be the best available information.

3. Coastal Special Operations

If I want to send a commando group ashore in a particular protected area, I will always try to choose the place in which natural features can help me. Ocean color information, especially turbidity must be considered.

4. Landing Operations

Not only ocean color itself, but the association of ocean color with currents and tides can help again at the point of planning and executing the operation.

5. Submarine Operations

Whether or not to station a submarine in a particular area, based mainly on tactical and strategic factors, is a decision in which ocean color can help.

If we can acquire the capability to know ocean color of particular areas of interest, it could become an important element in decision making. We can get near real-time data from OSC or from our own ground station.

However, I want to be clear that in my opinion, ocean color itself, even if used appropriately, will only make a small contribution to Argentine Naval Operations. We need to understand that the U.S. Navy has been working on developing empirical models to predict ocean phenomena (currents, waves, wind stress, etc.) since the 1930's, compiling huge amounts of information, performing thousand of predictions, verifying these predictions and improving the algorithm's coefficients when needed. So they are now probably ready to make better predictions based in satellite observations, from which ocean color will be just one factor. Because of the lack of experience we have in this field, I believe our goal should be to either get involved in projects that use SeaWifs data by committing our own oceanography expertise or promote this involvement to civilian scientists working in universities or advanced studies centers.

F. BENEFITS AND DISADVANTAGES OF USING SEAWIFS DATA WITH RESEARCH PURPOSES

1. Benefits

-We can use SeaWifs data for research without having to make a significant investment. A personal computer with internet capabilities could be enough to get

started. As usual, the better the technology, the better the product, keeping in mind that there is no particular urgent need that must be satisfied.

- Being involved in an international project led by NASA could be for our Navy the beginning of active participation in the field of oceanography from space and a worthwhile learning experience.

-This participation can help us in better understand space capabilities before deciding whether or not to buy data for operational use.

-Our involvement in such a project can create new space opportunities at the national and international levels.

-SeaWifs could provide a practical way to prepare Navy people for the future use of space assets.

-SeaWifs could help fulfill specific national oceanographic needs.

2. Disadvantages

- A SeaWifs demonstration project will require the commitment of at least one expert dedicated almost exclusively to the study of the relationship between ocean color and oceanographic phenomena.

- It will take time to reach some conclusions about the local phenomena associated with ocean color. Once obtained, the data should be analyzed, adequately processed and evaluated, and compared with *in situ* observations.

-It will require *in situ* measurements, which normally requires time from dedicated research ships and ships of opportunity. The information provided by SeaWifs data will not be conclusive in any way, if its not compared with corroborating

measurements of the real phenomena that occurred at approximately the same time.

G. THE NEXT STEP ABOUT USING SEAWIFS DATA

After learning how to manage SeaWifs non operational data, we should better be able to figure out whether or not this data will be useful for military operations. Assuming the decision is that we need to have ocean color data, then we will have at least two options:

-The installation of a ground station (a NASA approved HRPT). The requirements for this type of station are established by NASA as a function of capabilities for data storage and distribution (broadcasting) to the authorized users. Basically, these stations receive the data as planned by the NASA mission center and distribute this data when required. The cost of this station may vary, but can be estimated at $100,000 plus yearly maintenance and software upgrade (around $5000). They could also be moved on board oceanographic ships to support real-time observations. The process established to make sure that only authorized users can access the data is that NASA approved HRPT stations are authorized to receive broadcast LAC data by NASA. These stations will also be committed to distribution of data only to authorized users. Normally, this authorization will be for the retrospective use, meaning decryption codes will be provided at least 14 days after reception. LAC data will have to be recorded for later decryption. In addition to GSFC LAC facility, up to 12 stations at any given time my be licensed by NASA for

near real-time support for specific periods of time and purposes, and may receive the decryption codes in advance. [Feldman, 1996]

-The second option will be to buy data directly from OSC. This data will most likely be initially obtained and provided by the nearest approved HRPT, and OSC will provide the decryption codes in advance.

Whether or not we have an approved HRPT, to get data in near real-time for operational purposes, we must make an agreement with OSC. The only real need for a ground station is that the satellite can store all GAC data and a small selected amount LAC data which is downloaded at WFF, so the stored information will normally be about 4.5 Km resolution. All the information obtained through the approved HRPT is LAC so a resolution of 1.1 Km can be achieved.

The Argentine Naval Hydrographic Service, which is dedicated to conduct operative studies as well as scientific oceanographic research, would probably take advantage of this facility by performing projects related to shallow water oceanography without significant cost and with considerable benefits. Shallow waters would be of particular interest of the U.S. Navy, so it could also be possible to get cooperation from U.S. research centers involved in such studies.

Working with SeaWifs data could be a learning experience for the researchers involved on the project and the starting point to understand how satellites can contribute to Argentine oceanography. Based on our maritime heritage it would be a very useful contribution to the study of our coastal features, ocean circulation, seasonal nutrient displacements and other oceanographic studies.

IX. CONCLUSIONS AND FINDINGS

A. CONCLUSIONS

From this relatively brief study of satellite communications and remote sensing, I can draw several conclutions about the potential value of space assets to the Argentine Navy.

1. Use of space is definitely beneficial to the Argentine Navy

I analyzed, with more or less detail, different possibilities of using space in the Argentine Navy. Space assets are able to support a wide variety of military activities. Spatial resolution of remote sensors is increasing and relatively high resolution imagery is becoming commercially available, though low resolution imagery also has significant military utility. Useful communication bandwidth is increasing, and computers and technology provide the tools for transmission of large amounts of data, voice and video.

Commercial satellite communication systems like Teledesic promise a satellite-based internet and Iridium a full duplex voice capability. The use of satellite communications and remote sensing by military forces is no longer an exclusive capability of the few powerful nations. The technology is in the market, the information is in the market, and all nations (civil and military people) can get it and use it.

It is convenient for the Argentine Navy to take advantage of the space assets we can obtain today, in order to prepare for using the space assets we may need tomorrow.

2. Space assets are expensive

Cost is an important factor to consider. In general, the more powerful the satellite, the more expensive it will be. Typical cost to put a satellite in LEO ranges from $150 million to 2 billion,[1] and GEO ranges from $250 million to $2.5 billion [Wertz, 1996]. These values effectively eliminate consideration of exclusive Argentine Navy satellite programs.

For example, in the case of ORBCOMM, the projected cost for the entire program plus one year of operation was about $376 million. Assume that we buy one hundred SC's at the expensive price of $2,000 each and consider we pay an average $2,400 annually for each SC as a fee for using it. The total cost for five years of operation (ORBCOMM satellite's lifetime) will be $1.4 million, which is about 1/300 the cost of the total system.

Another example can be taken from CHALLENGE ATHENA experience. The cost of the six month operation during CA II was $3.5 million. In ten years of continuous operation, the Argentine Navy (using exactly the same system as the U.S. Navy did) could spend as much as $ 70.0 million. The cost of one GEO satellite could be $280.0 millon, so a CHALLENGE ATHENA type approach could give us comparable satellite capability for about one fourth the cost of developing our own system.

Of course these two examples are based on certain assumptions that must be carefully considered when drawing conclutions from my analysis. To get a more objective determination of what the best option would be from and economic standpoint (building,

[1] This cost estimate includes research, development, spacecraft launch, and operations during the satellite's lifetime.

buying, or leasing), I performed a sensitivity analysis, which will be at the end of this chapter.

3. Space assets are available

There is considerable diversity among space assets already available and those that will be available before the year 2000. Any country or military force interested in using space can find good opportunities for implementation in the international market at reasonable prices. Software, hardware, processed and unprocessed data, and new and old imagery can be acquired. Sometimes, when taking part in international projects, data can be obtained at little or no cost.

4. Space use requires understanding

Effective use of space requires significant skills and training. Space communications seems more understandable because commercial companies are now introducing some of the concepts in our daily routines. Direct Home Television and Very Small Satellite Antennas are becoming part of our daily life. However, proper interpretation of SPOT imagery or the combination of pictures taken at different times and by different sensors requires trained people and sophisticated computer aids. Developing competence in these disciplines requires significant time and effort, it is not possible to create experts in a couple of weeks.

5. Under certain circumstances, use of space for military purposes is accepted

The space-capable nations (first, second and third tier)[2] have been developing military applications for space assets since the launch of Sputnik in 1957. International treaties attempted to establish limits and ensure the normal development of space activities with peaceful purposes. However, treaties do not cover all aspects of space use. When can the military use civilian space assets with military purposes? Sometimes you can and sometimes you can not, depending on the side you are on. The U.S. use of civilian space assets during the Persian Gulf War encountered opposition from Iraqi allies and the use of the same assets by Iraqi forces encountered opposition from U.S. allies. Finally, the Coalition Forces used the same SPOT imagery that was denied to Iraq under the terms of the trade embargo.

Today, part of the U.S. Navy's communication systems is based on civilian satellites (for example CHALLENGE ATHENA is supported by INTELSAT satellites). Most of the world's navies already have INMARSAT systems installed on board their battleships, surely with the expectation of using it when needed, in peacetime or during war.

During wartime, the possibility of shutting down the services provided during peace time must be contemplated when selecting a space-based system controlled by a foreign country.

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[2] First Tier: United States . Russia
Second Tier: France, Great Britain, China, Japan , India and Israel
Third Tier: Brazil, Italy, Australia, Thailand, South Africa, Canada, Iran, Iraq and Pakistan.
[Lee, 1994]

6. The United States is increasing military use of commercial space assets

During the Persian Gulf War, U.S. military forces realized how important the contribution made by civilian space assets was. Today, the U.S. military is increasing considerably its use of civilian space assets. Technological advances in the commercial area produced more powerful satellites and associated ground systems, allowing the military to use some of those assets reliably and safely. Civil-military integration policies contributed to the development of military capabilities that use civilian technology.

7. Space is commercially attractive

The number of companies and countries interested in developing space programs have been increasing considerably as the world is realizing the advantages of using space assets. International policies are promoting new investments. Remotely sensed imagery helped provide security during the 1996 Olympics in Atlanta. It is also used to monitor the rain-forest evolution in the Amazon, to assess fisheries and pollution, and to monitor Nuclear proliferation. Global communications is now primarily through satellites. Most satellite services are available to anyone who is able to pay for them.

8. Space assets rapidly become obsolete

Satellite systems make extensive use of computer software and hardware. As computer technology evolves, satellites need to be updated in order to provide the same capabilities that can be found on earth. Satellites are designed to have a lifetime that can vary from two years (such as PANSAT)[Severson, 1995] to about seventeen years (such as INTELSAT VIII series)[Discover INTELSAT, 1997]. The design and construction of

a space system also takes time. For example, the High Energy Transient Experiment (HETE), for which some preliminary design studies began in 1991 [Martel, 1996], was launched late in 1996, two years past the initial scheduled launch (1994). Assuming that we are designing a payload, we are using a well known bus and launch vehicle, we are using the latest computer technology for our payload and our hypothetical satellite has an average lifetime of ten years, surely, the computer components will be clearly obsolete halfway through its lifetime. In the HETE example, we can not assume that designers waited until the day before launch to set up the computer system, so the truly recent technology was not on board. In the particular case of SPOT 2, which is still in use, the recording capability was the best obtainable at the time it was built. It does not mean the satellite is useless, but this sensitive part, can and will be improved in the new SPOT satellites. [Paige, 1996]

B. SELECTION CRITERIA

If space is a useful tool to improve our military capability, we must find the best approach to integrating space assets into our military forces.

I intend to find this "best approach" in the most objective way.

To do that, I am going to use a method presented during the International Conference on Engineering Design (ICED 81), in Rome, Italy, in 1981 [Pugh, 1981] The method basically consists of establishing all possible operational concepts (approaches) for the existing problem and a given number of criteria against which the approaches will be evaluated. Assuming one of the operational concepts as "the best" or "datum," we

establish a comparative analysis against the others, for each criteria, to see if they are better (+), worse (-), or the same (S).

At the end of these subjective comparisons, we will have a numerical value of pluses, minuses and "sames" that provides a relative comparison to a decision maker.

1. Operational Concept

"Concept" is defined in this case as a possible action we can adopt to achieve space capability in the areas of communication and remote sensing. From my point of view, there are four concepts that can be adopted:

a. Buy or lease service

This means buying or leasing a transponder from a particular satellite, national or international, for communications, or buying imagery from commercial remotely sensed data providers.

b. Bus plus standard technology based on requirements

This means the construction of an Argentine owned satellite by a third party who already has the bus and adding the sensors we require. The same company may also be responsible for the launch vehicle.

c. National Development

This assumes the entire system is developed by Argentina based on our own technological capability. We must assume that we will use a foreign launch vehicle.

d. No New Changes

This is the concept for which we decide not to use any more space assets than we are already using.

2. Criteria

Criteria is the parameters that will be affected by choosing a particular concept. In my example, I will consider that all the parameters have the same weight (importance), but this assumption is rather simplistic and subject to change. Of course, this would also change the final result. The parameters I believe we should care about are:

a. Cost

Cost could be a dominant factor, if we decide to weigh the parameters. The lower the cost, the better the option.

b. Time required to implement

The shorter the time required to implement, the better the option.

c. Capability

Capability refers to what we can do with the system. The more functions we can perform, the better the option.

d. Reliability

The system should be available when needed and perform as intended. (Table 2.1)

e. Security

The system should reduce vulnerability to interception and exploitation. (Table 2.1)

f. Timeliness

The sooner we can use the system when required, the better the option. This point should not be confused with time required to implement. Time required to implement means the time from the decision for use a particular asset (for example SPOT imagery) until its use becomes operational.

Timely means the specifying the application requirement to delivery of the final product. For example, obtaining imagery from a hypothetical Argentine-owned satellite, should take less time than buying SPOT imagery.

g. Flexibility

Flexibility refers to the capability of satisfying different missions. For example, it is very difficult to combine the instruments that satisfy the need for both remote sensing and communications in the same satellite. So, to have flexibility to support different types of missions, different satellites are usually required. In our case, I assume that leasing different services will provide more flexibility than developing only one class of satellite.

h. Interoperatibility

Interoperatibility refers to its ease of integration with other Argentine military forces and foreign forces.

i. Survivability

Survivability refers to its ability to work in the anticipated operating environment and its resistance to intentional aggression. Environmental "aggression" means the natural factors that can affect space assets, such as solar radiation and meteorites. Intentional aggression is the damages that can be caused by third party involved directly or indirectly in a given conflict against Argentina. For example, having our own satellite, in case of regional conflict, a hypothetical enemy can take all kind of measures against our satellite. If we are using a satellite belonging to a neutral country, the hypothetical enemy will have a strong incentive to avoid taking aggressive measures against the satellite.

j. Accomplishment of the objectives

This refers to the number Argentine Navy basic missions the concept can contribute to, and how well the concept can do it.[3]

k. Risk

The technological and economical risk of choosing one particular option.

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[3] The Argentine Navy basic missions were defined in Chapter II.

l. International Cooperation

This criteria assumes that international cooperation can help us develop our space programs. It does not mean that other countries will do our work for us. Rather, it means that by developing some kind of joint projects, we can get more technical support than by doing things ourselves.

m. International Laws

We want to respect all international treaties. The closer we are to the spirit of international treaties (whether or not Argentina has signed them), the better is the option.

n. Preferences

This refers to things that from my point of view would be preferred by the Argentine Navy.

o. International Policies

Independent of the international treaties, there are the national policies of the space systems owners, with respect to sharing space technology with foreign countries[OTA-ISS-607, 1994]. These policies are mainly based on keeping ultimate control over the space assets. The more independent we can stay, the better is the option.

Having defined the concepts and criteria, I will now develop the methodology to rank the concepts that best satisfy the criteria.

3. Analysis

a. First Iteration - Buying or Leasing

In the first iteration we assume that buying or leasing will probably turn out to be the best option, so we compare all the other options to that. The minus sign (-) means that for this criteria the option is worse, the plus sign (+) means that the option is better than buying or leasing, and the letter "S" means that it is the same as buying or leasing.

The way of thinking to consider one concept better or worst is briefly described for the numbered criterias.

1. Doing nothing will be cheaper but does not provide any benefits. We need to be careful with this type of indicator. For the same service, Bus plus Standard (B+S) or National Development (ND) will cost more than buying or leasing. Basically to justify such a development we need to be able to use the entire capability of the space system, which may not be the case.

2. If we decided to buy or lease the services that are already available, it will take less time than ordering the construction of a new satellite or building up for a national development effort.

3. In the buying or leasing case, although we need to accept what is offered, we have a wide array of choices. In the B+S and ND cases, we will probably be able to achieve more capability in one particular aspect.

4. Having a system we can control in all its phases will provide us with more independence than leased services will. Hence, it does not matter if the rest of the world likes us or not.

We will be able to use our system during crisis periods as well as during peace time. However, we need to recognize that the leader nations probably will have Anti-Satellite Weapon Systems, so if the decision of shut down an hypothetical Argentine satellite were supported by the international community, someone may be able to do this job. Such action will involve more compromise by the involved nations and is likely improbable if the satellite is being used to support regional military operations that only affect regional interests. For example, Israel decided to built its own system, because the military leaders did not feel confident with the support provided by the U.S. during the Yon Kippur War. [Lee, 1994]

5. Military systems are designed to support hostile war environments, so the protection mechanisms make military systems more secure than commercial ones. Nevertheless, the use of satellites in business requires some protection that can be exploited by the military.

6. If we own the system, we can use when we want. However, we need to worry about the capabilities of the satellite we own.

7. Either a single B+S or a single ND would be less flexible than the corresponding leased system.

8. B+S can be assumed compatible in technology and operation with foreign systems, if required. ND should be based on our own technology and may or may not be compatible.

9. The environment will be the same, but our own satellite could be more vulnerable to possible external actions during crisis situations than a leased service, because few countries would attempt a destructive action against a neutral country's satellite.

Politically, this can create more problems than benefits. Hence B+S has the same consideration as ND.

Table 9.1. Selection Criteria. Iteration N° 1

CONCEPT

N°	Weight	CRITERIA	Buying /leasing Service	Bus+Std based on our req.	National Development Tech. Sat's(Com's& RS)	No new action
1		Cost		-	-	+
2		Time to implement	D	-	-	+
3		Capability		-	-	-
4		Reliability	A	+	+	-
5		Security		+	+	-
6		Timely	T	+	+	-
7		Flexibility		-	-	-
8		Interoperability	U	S	-	-
9		Survivability		-	-	-
10		Accomplishment of the objectives	M	+	+	-
11		Risk		-	-	+
12		International Cooperation		S	-	-
13		International Laws		S	S	S
14		Preferences		+	+	-

Positive:	5	5	3
Negative:	6	8	10
Same:	3	1	1
TOTAL:	-1	-3	-7

10. More military objectives can be accomplished by having our own military satellites.

11. The amount of money required and the uncertainty of the benefits in a completely new arena constitutes a huge risk for B+S and ND.

12. B+S will contribute to international cooperation, because a foreign commercial company will build the satellite. ND will encounter more problems in obtaining technological support.

13. No law prohibits the use of the space for peaceful purposes. We can make use of the space in accordance with the international treaties, so I consider all options to be the same.

14. Any country would prefer to own and control their own satellite system.

b. Second Iteration

1. I consider that ND at the end should be more expensive than B+S, because it will take several years to achieve similar technology, which translate to higher cost.

2. As mentioned above.

3. Although we could be able to develop similar capabilities, the experience of the companies already working in that area is difficult to achieve ourselves. We must understand that one of the reasons why the U.S. is trying to achieve civil-military technology integration is because it is cheaper for the government and the product obtained is better.

4. Once the system is deployed, the reliability should be the same. However, considering the technological point of view, more advanced and mature technology like B+S case should be better with respect to ND.

5, 6 and 7. Depending on the design ND could be similar than B+S.

8. ND will be probably less compatible than standard technology.

9. Same as in table 9.1.

10. Designed under similar requirements, B+S and ND will satisfy similar objectives or missions.

11. ND implies more risk as a consequence of work in a relatively new field.

12. When talking about satellite development for military purposes not much cooperation can be expected from foreign countries.

13. Same as in table 9.1.

14. Our preference should be to be able to develop and operate our own systems.

Table 9.2. Selection Criteria. Iteration N° 2

CONCEPT

N°	Weight	**CRITERIA**	Buying /leasing Service	Bus+Std based on our req.	National Development Tech. Sat's(Com's& RS)	No new action
1		Cost	+		-	+
2		Time to implement	+	**D**	-	+
3		Capability	+		-	-
4		Reliability	-	**A**	-	-
5		Security	-		S	-
6		Timely	-	**T**	S	-
7		Flexibility	+		S	-
8		Interoperability	S	**U**	-	-
9		Survivability	+		-	-
10		Accomplishment of the objectives	-	**M**	S	-
11		Risk	+		-	+
12		International Cooperation	S		-	-
13		International Laws	S		S	S
14		Preferences	-		+	-

	Buying /leasing Service	Bus+Std based on our req.	National Development Tech. Sat's(Com's& RS)	No new action
Positive:	6		1	3
Negative:	5		8	10
Same:	3		5	1
TOTAL:	+1		-7	-7

c. Third Iteration

Table 9. 3. Selection Criteria. Iteration N° 3

CONCEPT

N°	Weight	CRITERIA	Buying /leasing Service	Bus+Std based on our req.	National Development Tech. Sat's(Com's& RS)	No new action
1		Cost	+	+		+
2		Time to implement	+	+	D	+
3		Capability	+	+		-
4		Reliability	-	S	A	-
5		Security	-	S		-
6		Timely	-	S	T	-
7		Flexibility	+	S		-
8		Interoperability	+	+	U	-
9		Survivability	+	+		-
10		Accomplishment of the objectives	-	S	M	-
11		Risk	+	+		+
12		International Cooperation	+	+		-
13		International Laws	S	S		S
14		Preferences	-	-		-

	Buying /leasing Service	Bus+Std based on our req.	National Development Tech. Sat's(Com's& RS)	No new action
Positive:	8	7		3
Negative:	4	1		10
Same:	1	6		1
TOTAL:	+4	+6		-7

The considerations in choosing better and worse are derived from the analysis above.

Table 9.4. Selection Criteria. Iteration N° 4

CONCEPT

N°	Weight	**CRITERIA**	Buying /leasing Service	Bus+Std based on our req.	National Development Tech. Sat's(Com's& RS)	No new action
1		Cost	-	-	-	
2		Time to implement	+	+	+	**D**
3		Capability	+	+	+	
4		Reliability	+	+	+	**A**
5		Security	+	+	+	
6		Timely	+	+	+	**T**
7		Flexibility	+	+	+	
8		Interoperability	+	+	+	**U**
9		Survivability	+	+	+	
10		Accomplishment of the objectives	+	+	+	**M**
11		Risk	-	-	-	
12		International Cooperation	+	+	+	
13		International Laws	S	S	S	
14		Preferences	+	+	+	

Positive:	11	11	11
Negative:	2	2	2
Same:	1	1	1
TOTAL:	+9	+9	+9

d. Forth Iteration

When choosing to not take new actions, we are assuming a conservative position with no cost, no risk, and no problems. In reality the cost and the risk of letting the opportunity to improve our general capability pass could be much more expensive in the long run than it seems to be in the near term.

e. Summary

The last table (Table 9.5) show us that there is no clear absolute winner in this analysis. The final values for B+S and B/L are the same, but the factors in favor and against each other are different. I did not assigned weight to the different criteria, but at the time to make a decision for an specific application, cost or security could be much more important than flexibility or personal preferences.

Table 9.5.

Iteration	Buying /leasing Service	Bus+Std based on our req.	National Development Tech. Sat's(Com's& RS)	No new action
1	Datum	-1	-3	-7
2	+1	Datum	-4	-7
3	+4	+6	Datum	-7
4	+9	+9	+9	Datum
Total:	+14	+14	+2	-21

What it is clear from my point of view is that the option of not trying to use the space will be the worst. Although we can avoid taking a risk, we surely will be falling behind in technology, and it will take much more time for our navy to catch up from this situation.

This analysis attempted to make objective the point of view what was initially subjective. The concept selection criteria provides, in my opinion the appropriate tools to do that.

X. RECOMMENDATIONS

A. RECAPITULATION

Throughout the preceding chapters I presented a number of different space-related issues. I started by determining the Argentine Navy Missions and Requirements (Chapter II). Using this requirements as a guidelines, I focused my attention on commercial communications and remote sensing. I dedicated the third and fourth chapters to the importance of GEO and LEO satellites, some of which are already on the market and some of which are coming in the future. In my search, I emphasized the use of civilian communication satellites in the military, because I considered it to be the best way to achieve capabilities we do not have. Considering that the U.S. space requirement assets are different from ours, I used the U.S. examples of civilian applications as a proof of their feasibility. I abounded in diversity of topics and technical data to illustrate how expansive the subject of satellite communications is and how much interest there is in it. I chose the ORBCOMM system (Chapter V) to provide a more detailed example of one possible use of civilian communication satellites in our navy.

With similar criteria, I entered into the area of remote sensing (Chapter VI) and discussed the possible military applications and presented what we can get today. I chose SPOT (Chapter VII), the commercial remote sensing leader, and SeaWifs (Chapter VIII), a satellite dedicate to ocean measures, to show how civilian remote sensing assets can be used for military purposes. In the preceding chapter, along with my findings and conclusions, I presented in the most objective manner the reasons why I consider that the

use of commercial space assets is the best way, or maybe the only way, for the Argentine Navy to continue using space. In this chapter, I want to conclude my study with a plan to keep the Argentine Navy current with respect to deriving benefits from using space assets.

B. GENERAL STEPS TO IMPROVE ARGENTINE NAVY SPACE CAPABILITY

1. Define Argentine Navy Space Objectives

As we saw in Chapter II, Argentina already has a National Space Plan that serves as the focal point for national space development. As a military force, we need to develop clear and achievable Navy Space Objectives. In same aspects, our goals are very close to the National Space Plan. In others, military needs are not taken into account, so we must develop our own resources to satisfy them. I started my thesis defining what I consider to be the Argentine Navy needs (page 14) in a broad sense. Still, I must emphasize that the Argentine Navy must determine exactly what level of tactical support it requires to accomplish its missions. I also think that we need to separate our smaller goals from our larger national goals. Through examples, I demonstrated that space assets are useful for many military applications. The next step is to define which of these applications the Argentine Navy really wants to take advantage of and how much it is willing to pay.

Independently of the provider, the Argentine Navy will be consumer of space products, so we need to maximize our capability and minimize our cost. To do that, I believe that the Argentine Navy must assume an aggressive, but realistic Navy Space policy; aggressive in terms of trying to use whatever it can to increase operational space capabilities, and realistic in terms of expecting no more than we can afford (but no less).

Of course, it would be the best if the Argentine Navy requirements can be satisfied by space systems that Argentina owns or controls, but we move ahead as much as possible in the direction of satisfying our need until these national means are available.

2. Emphasize Argentine Navy Interest in U.S. Space Cooperation

I believe that one of our goals should be to obtain U.S. cooperation in space. Although space is a sensitive issue, military programs are classified, and it is difficult to share certain space-based resources with international partners, there are some areas in which it could be convenient for the U.S. to have allied countries prepared to carry out basic activities in space. For example, if Argentine military forces were involved in a combined drug trafficking control, which may include Navy ships, Marine Corps or Naval Aircraft, the appropriate and timely distribution of imagery obtained by U.S. systems can contribute significantly to this mission, which would benefit both countries. It would be convenient to clearly establish Argentine Navy space-related requirements in cooperation with the U.S. Navy.

Since 1990, the Argentine Navy has had an agreement of mutual cooperation between the former Defense Mapping Agency (now called the National Imagery and Mapping Agency (NIMA) and the Servicio de Hidrografia Naval, oriented to cartographic and geodesic purposes. I consider it convenient to reinforce these agreements, after an analysis of what may have changed from 1990 to the present.

3. Define technical direction and investment

Once we determine what we want, we must go out and get it. There is technology available that could be reasonably applied to virtually all of our needs, but we must make the right choices, which is probably the most difficult part of the process. As intelligent consumers we need to let the commercial companies know what we are interested in and see what they can do for us and at what prices. With the recent proliferation of commercial companies involved in space business, we must expect that the prices will continue to fall and the quality of the services to improve.

The acquisition process is never easy. If we expect more than the basic services from a given product, we will have to pay for the product itself as well as for the cost of integrating it into our operations. Before committing our valuable resources to any project, we must test whenever possible to see if it really satisfies our requirements and evaluate its limitations and capabilities. One important consideration is that there are more commercial and military products available than we see in the normal course of our daily operations, so we must make the effort to search for products that may better satisfy our needs.

4. Space awareness

Space is a relatively new subject in the Argentine Navy. To take full advantage of space we must educate key personnel. This education should be divided into different areas. As the reader probably appreciates, the weakness of this thesis resides in the

impossibility of covering this topic with more breadth. The same will happen if we try to assign all space responsibilities to the same person.

How should we assign specializations to space personnel? At the officer level, university preparation is mandatory. Without having a reference to compare it to, that the masters degree programs developed at Naval Postgraduate School in Space System Operations and Space Systems Engineering provide the appropriate level of technical preparation to understand the problems of space from a naval point of view. At lower, but more specialized levels, the study of space should be divided into remote sensing and communications. Remote sensing should be sub-divided into operational intelligence and meteorology. The Communications area should be sub-divided into communication systems and navigation systems. However, the final goal must be the integration of the sub-divisions to support the C^3I/C^4I structure.

Where can we prepare our personnel? This work should be done both inside and outside of our navy using all available resources. Commercial companies provide training on particular systems as part of a selling the product. Another way may be to establish agreements with university, government, or civilian users of space systems.

It is important to impress upon Argentine Navy officers the importance of space in the military. It is necessary to include space issues at different levels of our Naval education, and to offer our young officers incentives to pursue their interest in space as a way to facilitate their understanding of ongoing technological developments.

5. Inter-service cooperation

The need for use of space is not only a Navy problem. Given a number of similarities between the Army and Marine Corps, or between Air Force and Naval Aviation, what could be useful for one branch of the forces could be useful for the another. Because space is expensive, combining the efforts of two or more Argentine military forces can be one way to reduce costs and increase benefits.

C. PRACTICAL STEPS TO IMPROVE ARGENTINE NAVY SPACE CAPABILITY

1. SeaWifs

It may be possible to encourage a couple of specialists from the Servicio de Hidrografia Naval to develop a scientific project compatible with Argentine Navy and NASA goals. This action can be very positive and provide the benefits mentioned in Chapter VIII. Data collected for scientific purposes may be acquired under the terms established by NASA in its "Dear Colleague" letter.[1] I recommend this as a first step rather than applying for a HRPT ground station, which could be the second if it were considered really justified.

2. ORBCOMM

It would be convenient to establish an official contact with ORBCOMM U.S. I believe that the system can provide interesting applications. However, before making any important decision, or before any commitment of money, we need to test applications of the system in our operational theater to determine the effect of its limitations on our

[1] Administrative form to apply for the use of SeaWifs data on a scientific basis. [Feldman, 1996]

operations. Because it is a commercial system, we need to take advantage of its commercial characteristics by investing as a normal user. We should not yet consider Joint ventures. We are not going to use it before the entire constellation is set up, and I do not think that the system deserves more than a minimum investment. It could be easy and inexpensive to install at least one Subscriber Communicator on board of our Frigate A.R.A. "LIBERTAD" to test its features.

3. Remote Sensing Imagery

We should procure the hardware and software required to create a Navy Geographic Information System (GIS) to be used for operational purposes. GIS is a computer system capable of assembling, storing, manipulating, and displaying geographically referenced information. GIS can use information from many different sources like maps, aerial photography and satellite images. With a GIS, we would be better able to manage our existing data base and integrate new data into it.

Another interesting alternative may be the acquisition of simulators to be used in training and mission planing. One of the systems that may be studied is the one I mentioned before, PowerScene.™ PowerScene™ is a three dimensional flight simulator and reproduces geographic areas as a function of the resolution of the imagery data installed in the data base. Before making any investment, it is necessary to clearly define which information is going to feed the system, how is going to be obtained and the compatibility of the data format with the software selected to manage it

4. Network Development

I strongly consider, that in order to understand how space assets could contribute to our C^3I/C^4I structure, we need first to fully understand the limitations of the terrestrial based communication systems. Computer networks, a relatively new technological issue in Argentina, are mandatory when preparing for using data from future space based systems. Teledesic for example, when ready, will provide a space based internet with inter-linked satellites and the ability to reach remote, isolated areas. This system may be useful for deployed ships or forces in operation.

APPENDIX A

ARGENTINE NAVY UNITS

SURFACE UNITS

Destroyer A.R.A. "Hércules"
Destroyer A.R.A. "Santísima Trinidad"
Destroyer A.R.A. "Almirante Brown"
Destroyer A.R.A. "La Argentina"
Destroyer A.R.A"Heroína"
Destroyer A.R.A. "Sarandí"
Frigate A.R.A. "Drummond"
Frigate A.R.A. "Guerrico"
Frigate A.R.A."Granville"
Frigate A.R.A."Espora"
Frigate A.R.A. "Rosales"
Frigate A.R.A. "Spiro"
Frigate A.R.A. "Parker"
Frigate A.R.A. "Robinson" (in construction)
Frigate A.R.A. "Gómez Roca" (in construction)
Minesweeper A.R.A. "Neuquén"
Minesweeper A.R.A. "Río Negro"
Minehunter A.R.A. "Chaco"
Minehunter A.R.A. "Formosa"
Patrol Craft A.R.A. "Murature"
Patrol Craft A.R.A. "King"
Patrol Boat A.R.A. "Baradero"
Patrol Boat A.R.A. "Barranquera"
Patrol Boat A.R.A. "Clorinda"
Patrol Boat A.R.A. "Concepción del Uruguay"
Patrol Boat A.R.A. "Zurubí"
Fast Patrol Boat A.R.A. "Intrépida"
Fast Patrol Boat A.R.A. "Indómita"

AUXILIARY SHIPS

Patrol Boat A.R.A. "Irigoyen"
Patrol Boat A.R.A. "Teniente Olivieri"
Patrol Boat A.R.A. "Gurruchaga"
Patrol Boat A.R.A. "Alferez Sobral"
Patrol Boat A.R.A. "Somellera"
Patrol Boat A.R.A. "Suboficial Castillo"
Transport A.R.A. "Canal de Beagle"
Transport A.R.A. "Bahía San Blás"

Transport A.R.A. "Cabo de Hornos"
Transport A.R.A. "Tulio Panigadi"
Transport A.R.A. "Astrafederico"
Transport A.R.A. "Río Gallegos"
Transport A.R.A. "Astravalentina"
Transport A.R.A. "Ingeniero Krausse"
Frigate A.R.A. "Libertad"
Icebreaker A.R.A. "Almirante Irizar"
Hidrografic Ship A.R.A. "Comodoro Rivadavia"
Hidrografic Boat A.R.A. "Cormorán"
Hidrografic Boat A.R.A. "Petrel"
Oceanographic Ship A.R.A. "Puerto Deseado"
Amphibious Landing Ship A.R.A. "San Antonio"

SUBMARINES

Submarine A.R.A. "Salta"
Submarine A.R.A. "San Luis"
Submarine A.R.A. "Santa Cruz"
Submarine A.R.A. "San Juan"

MARINE CORPS

2nd Marine Infantry Battalion BIM2
3rd Marine Infantry Battalion BIM3
4th Marine Infantry Battalion BIM4
5th Marine Infantry Battalion BIM5
Logistic Support Battalion
Marine Field Artillery Battalion
Amphibious Vehicles Battalion N° 1
Amphibious Commandos Company
Marine A/A Battalion
Marine A/T Company
Communications Battalion
Río Gallegos Naval Detachment
Río Grande Naval Detachment
Amphibious Engineer Company
Anphibius Support Group

NAVAL AVIATION

Combat Airplanes
SUPER ETENDARD
Exploration Airplanes:
L-188T/E/P ELECTRA
B-200 BEECHCRAFT SUPER KING AIR

ASW Airplanes
S-2T- TURBO TRACKER
Helicopters:
SH-3D SEA KING
AS-555 FENNEC
AI-03 ALOUETTE III
Transport:
F-28 FOKKER Fellowship
PL-6 PILATUS PORTER
Instrucction:
T-34C TURBO MENTOR
MB-326 AER MACCHI y GB Pelican

APPENDIX B

THE NATIONAL SPACE PLAN [1]

Table of Contents

[1] Refereed to the Argentine Space Plan called The National Space plan

1. INTRODUCTION

Argentina may be labeled as a "space country", considering that it features as one of the countries that makes and will make intensive use of the products from space science and technology. This occurs because:

- It covers an extensive geographical territory, ranging from the tropic to the pole.
- Economic activities in Argentina are strongly influenced by extensive primary exports (agricultural, fishing, forestry and mining products, plus hydrocarbons).
- Its society has a development level that requires everyday use and exchange of detailed and quantitative data on its own structure and economy.
- The distinctive distribution of its population demands an intensive use of telecommunications.
- Its large productive areas are vulnerable to natural and anthropogenic catastrophes.
- The regional and international links and commitments undertaken by the nation will oblige it to generate and use goods and services deriving from space science and technology.

From the above points, it arises that, in view of its own conditions, Argentina is making and will make use of products derived from space science and technology and, consequently, a definition is to be made on how to have access to them in the future. Considering its level of technical and economic development, its projection towards becoming a producer and an active user of such technology appears as logical. An "active consumer" of goods with a high technological content is understood as that having the necessary technical capacity, when purchasing, to exert influence upon the conceptual definitions and the advantages of what is being purchased. Any other strategy would not only mean misusing the important national patrimony in inventive and well trained human resources, but would also place the country in the unfavorable condition of exchanging primary products by other with a high added value, thus creating a weak situation in terms of commercial exchange.

2. CONCEPTUAL FRAMEWORK

The produce of space activities

Primarily, the social benefits deriving from space activities result from two products:

- The data generated by space applications and the means for its transmission.
- The means for exploration and for the peaceful use of ultraterrestrial space.

The various phases in space activities sense, collect, transmit, store and process data of highly different nature. This is why, presently, space activities are also generators of hardware and software means for the performance of such tasks.

The important participation of space technology in telecommunications is an example of this fact. Additionally, the contribution of data detected by remote sensors is to be taken into account. Both its volume and quality, as well as the areas that will require its use, tend to grow and diversify in the near future.

Once data is delivered to society, it gains added value as it is systematized and prepared for its use in everyday decision-making by the government or by the production sectors. Society houses a large number of enterprises -ùwhich may well be called "information companies"-ù that perform these tasks, both processing data and enhancing them in different ways.

The set of steps encompassing space data generation, transmission, processing and use is called ***"Space Information Cycle" (SIC)***. Along this cycle, space activities operate either as use promoters or as suppliers or consumers of both the data itself and the means for its production, transmission, elaboration and storage.

Humanity is presently facing problems in making its own subsistence compatible with the planet by attaining equilibrium among its seas, its atmosphere and its reserves of natural resources. Growing industrial, agricultural and mining activities worldwide have raised serious concern with regard to a tentative alteration of geophysical balance in the atmosphere and the oceans that might result in a global heating of the planet. In addition to these processes, highly significant threats are arising concerning contamination and the loss of biodiversity. The *SIC* has already proved to be an unreplaceable element for designing strategies for the supervision and control of these processes with such enormous social and economic impact. In this field, an analysis must be made of the alternatives offered by space and by space technology towards reaching structural solutions to the anthropogenic threats affecting the Earth's environment.

The second important product of space technology is a means for exploring and exploiting ultraterrestrial space. This means will definitely play a leading role in the long term. To a good extent, spacecraft is presently a contribution to the *SIC*, since it is used in locating, in space, the means needed for data sensoring and transmission. In the long term, this means for exploration and exploitation of ultraterrestrial space will become an independent resource of peaceful use, constituting an additional environment where humanity will be able to develop diverse activities. The extreme vacuum, the absence of gravity and the existence of radiations, which are shielded by atmosphere on the Earth's surface, make space appear as an adequate and uniquely-featured environment for facing certain undertakings, such as the production of materials or chemical compounds, or even power generation.

Scientific programs

Space activities demand significant intellectual investment. Profiting from the data collected by means of space technology resources, the development of space communication systems or the access to and use of the ultraterrestrial space for other purposes require process formulation and development and the management of data obtained through scientific methods or within the framework of scientific research projects.

Technological progress in the space field occurs everyday and is constantly providing new alternatives for the use and exploitation of ultraterrestrial space. This technological development is bi-directionally related to several scientific fields. It does not only allow for further basic research; on the other hand, it does also allow for scientific projects that are readily applicable to economically meaningful technological applications and developments that produce a relevant impact upon production sectors.

Within this context, *space activities must be kept closely linked to research and development teams, involving the promotion of these activities as a part of their ordinary programs, in the understanding that the resources applied for their execution constitute an investment whose return is part of the produce from space activities.*

Areas for application of space activities

Argentina is already using some of the links in the ***SIC***. Satellite telecommunications are already a fact, while several sectors are regularly using remote sensed data. Satellite telecommunications are used commercially in the provision of telephone services through switchboard networks and of television services. Highly sophisticated computer networks and other requirements in the field of data transmission lead to foresee an extension of the present horizon in telecommunication services, for which space technology has much to offer. The main user of remote sensed data is the public sector. These applications are aimed to expand through the execution of environmental control and surveillance programs. The following are the sectors of economical activity on which the ***SIC*** has a most significant effect:

1) Telecommunications.

2) Use of global positioning systems.

3) Prevention, evaluation and follow-up of natural and anthropogenic disasters.

4) Monitoring and usage of natural resources.

5) Remote detection and control of industrial parameters.

6) Cartography and cadastre.

7) Supervision and quantification of agricultural and forestry production.

8) Fishing, exploitation and surveillance of coastal and oceanic resources.

9) Studies on environmental quality, degradation and contamination.

10) Local and global meteorological studies.

11) Utilization of soil and underground resources.

12) Design of new methods for development management and administration at a regional scale.

13) Global change.

Sustenance and economic benefits of space activities

The assessment of the benefits deriving from an innovative activity does not constitute a problem solved beyond any controversies, especially for economies such as our country's. However, studies have been performed aimed at considering them as medium- and long-term investments, thus estimating an internal return rate associated to research and development activities, innovation and related services. On the basis of these estimations, it may be stated that a space program in Argentina is not only potentially sustainable by the local economy; it may also result in significant benefits, as far as it is undertaken within certain patterns.

There are three ways in which space activities may be considered in order to justify a public investment program in this field. They may be analyzed: a) as managers and promoters of development issues that are transferable to commercial activities; b) as research, development and innovation tasks; and, c) as direct producers of commercially valuable goods and services.

Space activities have proved to be a setting for the development and full growth of new technological concepts that, in a further stage, when adopted by the production sectors in society, have born the rigor of a free and competitive market. The telecommunication systems based on artificial satellites are the best example of this; after going through a stage of experimental development, they were assimilated by the companies providing such services and these companies were the ones taking care of the diffusion and application of this new technological concept. The present trend in this field is that, in the short and medium term, the promotion of advanced matters in this technology must remain within governmental agencies, while development work related to the optimization and service expansion is left in the hands of the private sector. Service is presently aimed at giving priority to satellite voice and data telecommunications, a field in which CONAE's responsibility is limited to the offer of services as a "space architect" (selection of design and engineering options). Contrarily, CONAE shall have to develop technologies associated to other non-massive data transmission services involving economic significance and social relevance (education, safety, isolated human settlements, maintenance of extensive networks such as gas pipelines, high-voltage lines, etc.).

There is an area in which space activities have proved to be a fertile means for the development of new technologies with a considerable commercial impact: that of the global positioning systems, which will play a leading role in the assistance to and control of air, sea and land transportation. This technology is aimed at acquiring commercial importance in the very near future. .

The benefits deriving from space activities in research, development and innovation are indirect. When considered as such, space activities may be deemed on an equal footing with basic scientific work. An assessment of the secondary economic effects of activities of this kind was performed by the European Center for Nuclear Research (CERN). This Center is the international laboratory of excellence in physics and in theoretical and experimental research, considered as the most important in Europe.

The following factors were taken into account for the quantification of effects:

- Suppliers qualification and development.
- Innovation among supplier industries.
- New product development.
- Quality improvements.
- Creation of demand for new products.

The studies performed proved that there is a factor of significant benefit, which is directly attributable to the effort performed in trying to comply with the contracts made with the CERN.

A similar study was carried out by the NASA concerning the Apollo project. In this case, technical matters are supplemented by the diffusion of new management concepts that were applied in this project. The assessments did also show a benefit factor that resulted to be even higher than that obtained by the CERN.

These data cannot be transferred without any modification to the Argentine situation, considering that their global usefulness depends on the degree of applicability of the development projects in the local industrial and economic media. Considering the early stage of development of our Space Program, this information must be taken as an indication of the potential benefits obtainable from activities in this field, as far as it is properly linked with the supplier industries.

Space activities are also producers of goods and services with a commercial value. If telecommunications, already analyzed as from another viewpoint, are excluded, mention must be made of remote sensing activities. Nowadays, the major segment of demand in our country is the public sector. Although this fact is not expected to change drastically in the near future, it may be foreseen that, in the medium term, some areas of the data obtained by remote sensors will go into a commercial stage and will be handled somehow as satellite communication systems are managed today. Meanwhile, this market should consolidate in our society through the creation of an independent entrepreneurial sector highly specialized in the use of these means. Thus, it would produce a simultaneous benefit to society through the diffusion involved in the use of such data. These facts being taken into account, consideration must be given to a first promotion stage, which will require support to this activity from the public sector and, at the same time, a stimulation of private participation in any possible way.

The areas whose profiles show a most direct economic impact in the short and medium term are:

- The follow-up and quantification of agricultural and forestry production.
- The follow-up and surveillance of fishing activities.
- The supervision of floods and natural disasters.
- The evaluation and survey of soil and underground exploitation works.

- The monitoring and supervision of environmental problems.

Additionally, there are other secondary markets connected with remote sensing that, due to the early phase of their use in the country, are hard to estimate:

- The market of geographical data systems and their related data bases (Applied Data Systems, ADS).

- Global climatic reporting and forecasting.

- The market of special sensors.

In addition to constituting a valuable base of general information, the use of teledetected data in agricultural exploitations may give way to more accurate forecasts of future harvests, to a better control of promotion loans and of tax collection, and to a better use of subsidies on natural disasters. As an example, it may be mentioned that, when correlated with climatic factors, a detailed historical data base on agricultural production should serve as a basis for a market of agricultural insurances, an activity that is now practically non-existent.

In the fishing area, the use of satellite data may result in more effective campaigns and in fuel savings due to the satellite positioning of areas of high fishing density. Appropriate satellite data is also indispensable for the surveillance and control of fishing licenses concerning operations in the Argentine Sea and for the supervision of over-exploitation of fishing resources. Remote sensing in the mining field would contribute with significant savings in exploration campaigns.

3. POLICIES, JURIDICAL MATTERS AND INTERNATIONAL RELATIONS

The National Space Program is to be understood as a major national project. The actions aimed at attaining its goals imply direct or indirect participation by an endless number of human teams from the production areas, the government, the academic sector and the national Science and Technology system.

The explicit incorporation of the various sectors mentioned above, involved in specific commitments, is expected to occur as actions start being implemented. In other words: the objective is that the National Space Program be one of the national projects allowing for the concentration of means and resources and for the confluence of diverse human resources towards its accomplishment.

Bases

The development of space technologies to be envisaged within the framework of the National Space Program shall produce the maximum and most immediate social and economic return. This can be attained by focusing efforts towards its use in:

- Contributing to ***education*** and to ***improving the population's quality of life***, particularly in distant and marginal areas.
- Creating ***new capabilities and sources of employment*** at industries producing goods with a high added value.
- Obtaining ***advantages for the local production system***, thus allowing for the insertion of our industry into a highly competitive international market.
- **Promoting new businesses** that allow for an expansion of the national production scope.

The most suitable way to attain such goals is the application of a strategy involving the ***concentration of efforts*** and specialization, through the identification of well- defined objectives and of attractive technological and commercial spots, where an ***international level of excellence and of originality can be reached and maintained***.

The Space Program must be considered as a ***part and continuation of the efforts for technological development already performed in our country***. As from its very start point, it must profit of an important threshold of scientific and technological knowledge and undertakings already gained through the activities performed by the former CNIE (National Commission of Space Research) and by other local scientific and technological institutions, such as INTA (National Institute of Agricultural Technology), INTI (National Institute of Industrial Technology), CONICET (National Council of Scientific and Technical Research), CNEA (National Atomic Energy Commission), universities and other agencies. The Space Program must be supported by a flexible research and development infrastructure optimizing CONAE's infrastructure and by the use of resources assigned to space activities. For such purpose, it must be interactive with whichever public and private institutions and work teams are deemed necessary, by means of a flexible organization that may be adapted correspondingly with the progress attained.

Guidelines

- Offering society a complete cycle of space data, promoting their best utilization.

- Developing space technologies for environmental protection.

- Promoting the use of space technology for social, production, scientific and educational purposes.

- Developing light satellites for remote sensing, scientific use and communications, supplementing the available international offer and responding to specific national demands.

- Promoting actions supplementing those in the private sector concerning initiatives with a high technological and innovation content, or the use, diffusion and utilization of space data.

- Encouraging the training and qualification of human resources and of organizations contributing to and participating in the Space Program.

- Assisting in promoting national participation and initiatives aimed at enhancing the tasks of international forums where juridical regulations related to space activities are discussed and prepared.

- Promoting international cooperation actions, looking forward Argentine participation in multinational cooperation programs converging with the local long-term policies.

- Favoring joint international actions and programs with shared goals that contribute to regional integration within the framework of MERCOSUR.

- Complying with the legal mandate of being present and of contributing with the technical and scientific elements needed for shaping coordinate and joint actions with other State agencies.

Juridical matters and international relations

International cooperation is a key issue as far as space technology is concerned. Argentina has already had a lengthy and active cooperation with Brazil, France, Germany, Italy and the United States, and is presently planning joint projects with Denmark, Spain and other countries. CONAE shall encourage these cooperation lines, as far as they converge with the development work scheduled in the National Space Program and involve concrete projects aimed at well- defined goals. Any initiatives or proposals for international cooperation implying diversification of efforts shall be considered by CONAE as of secondary importance.

CONAE will place special emphasis in strengthening regional cooperation in space matters. It will look forward to expanding the goals and to optimizing the tasks scheduled in the present Program, encouraging active cooperation within the framework of MERCOSUR. It will promote the use of supplementary infrastructural resources and development means in the region, schedule the performance of mutual assistance actions, contemplate supplementary development work and explore the possibilities for the performance of joint space missions.

With its own actions and as far as it converges with its objectives, CONAE will support the initiative for research on the Global Change, which is presently acquiring institutional and international-cooperation dimensions, with the IGBP (International Geosphere Biosphere Program) and other institutions. This research work would demand a highly significant effort in the space field and is of interest for a rational management of renewable natural resources and of the region's biodiversity, as well as for forecasting

social and economic changes that may affect the country and the hemisphere.

4. SCHEDULED SPACE ACTIVITIES

The main areas of space activity foreseen in Argentina involve both scientific/technological research work and applications.

These scientific and technological projects will allow for attaining progress in the preparation and management of space missions, as well as in the design of satellites and of on- board instrumentation. Likewise, this activity will allow for consolidating international cooperation links in the space field.

Application activities will be primarily devoted to a remote sensing program and to telecommunication matters supplementing the local and international offer in data, voice and television communications.

Activities in remote sensing include both the reception and distribution of images from international systems and our own image generation within the optical range (visible and infrared) and microwaves, appropriate for the local requirements and of a great social relevance.

As a part of the land infrastructure, provisions are being made for the installation of a Multi- purpose Ground Station aimed at satisfying both remote sensing and radioastronomy demands.

Concerning the production of our own images and data, provisions have been made for the development of satellite systems to be compatible with the scientific and technological research work, through the line of light satellites SAC (Satellite for Scientific Applications).

Similarly, an attempt will be made to develop conceptual parameters leading to the design of sensors fit for solving unsolved problems or for obtaining new types of economically valuable data.

The development of satellite systems involves both the design of chambers and sensors and that of computation instruments required for receiving, storing and processing the data produced, thus integrating the main links of the ***SIC***. The use of the infrared spectrum is relevant for the measurement of (soil and water) surface temperatures and for diverse agrometeorological and oceanographical applications, as well as for environmental monitoring (forest fires and volcanic activity). With regard to the visible optical range, the medium term trends in the international arena involve an increase in the number of spectral observation channels, so as to make it more specific and versatile to various applications, which has been contemplated in the third SAC satellite. Finally, as a long-term development objective, studies are to be performed on laser applications in space.

In the short term, the remote sensing program will be supplemented with observations in the microwave range by means of a radar. This is an important method, since it allows for capturing images regardless the solar light on the site and the meteorological conditions, since it goes through the clouds. This is particularly relevant for the monitoring of the Argentine Sea, the Province of Tierra del Fuego and the Antarctic Sector, which are systematically covered by thick cloud layers. Radar observation can also be used for soil studies (particularly for soil humidity measurements), a subject in which INTA has a long and valuable experience. Microwave range observations are obviously applicable in matters related to the national agricultural production and to the monitoring of fishing in the South Atlantic.

The microwave observation program is a start point for the analysis and development of alternatives to the low-consumption radar, a major condition if the best use is to be made of the experience gained with the SAC line of light satellites. This observation program shall be carried out with the SAOCOM satellite family series (Satellites for Observation and Communications). In the latter, the radar's useful load shall

be shared with that in communications, as described below.

The applications foreseen in the field of communications are aimed at solving deficiencies in extensive areas of the country as far as communication elements are concerned. An adequate use of space communication technologies may allow for solving many of the problems being suffered in rural environments and schools, in remote police stations and in distant hospitals and health- care centers. They are also applicable for the maintenance of extensive power distribution networks and gas and oil pipelines. This service must be aimed specifically at data transmission, electronic mail, connections with isolated settlements, links with low-cost land platforms for the collection, control and recording of the most diverse types of data, such as agrometeorological, environmental, hydrological and industrial application data. These matters are marginal for the telecommunications market in private hands, but they are considerably significant as from strategic, economic and social standpoints. Simultaneously, economically-sustainable innovative technological development projects may be carried out in this area. The latter shall be installed on SAOCOM type satellites.

The orbiting of satellites foreseen in previous programs shall be performed using the services of access to ultraterrestrial space available on the basis of international cooperation agreements or by means of contracts undersigned with suppliers of these services. Provisions have been made for reaching other uses of ultraterrestrial space. A long-term project involves the development of per se means, or preferably in cooperation, for access to space with new generation spacecraft. In this field, work will only be started with the exploration of conceptual alternatives, with provisions for some partial performances within the first decade in the next century.

5. PERFORMANCE OF CONAE

Organization

The performance of CONAE shall be organized in the form of ***projects*** and ***activities*** within a matrix structure in which activities are formed as columns in the matrix, while projects represent the horizontal lines in the same. Both activities and projects will be redefined periodically, in a dynamic manner, thus regarding some as finished and starting other.

Each ***project*** is understood as encompassing a set of actions involving a start point and as finished when a definite goal is attained at a given time. Every project will have its own schedule, budget and financing. Considering that each one of them may give way to or require one or more activities, their budgets must contemplate the contribution required for the coverage of their share in the fixed costs involved in maintaining the institution's regular activities.

Activities represent actions of a technical or administrative type that are performed either temporarily or regularly, without a definite completion date. Activities do also include regular technical services and the performance of study, research and development programs that serve as a support to projects.

It is worth, here, introducing the concept of "mission", involving all the tasks undertaken in connection with a given incursion into ultraterrestrial space. As a general rule, reference will be made to missions associated to satellites, this concept including feasibility studies and design, as well as their construction, launching and further operation. It also includes all the tasks performed for their utilization in the scientific arena or for remote sensing and communication applications. As it may be seen, a mission involves both projects and activities. Excluding exceptions, this concept shall not imply any budgetary consequences, since it is introduced for the single purpose of facilitating control over management in the execution of the Plan.

Courses of action

The projects and activities defined above constitute a scheduled program of actions to be faced by CONAE. For planning, discussion and analysis purposes, they will be considered as encompassed in five ***courses of actions***, thus associating each one of them to an equal number of broad segments in space activities, as follows:

A) Land infrastructure.

B) Satellite systems.

C) Data systems.

D) Access to space.

E) Institutional development and basic tasks.

A - Land infrastructure

This course of action contains all the tasks performed by CONAE with regard to ground stations for follow-up, telemetry and control of Earth links with satellites or spacecraft, laboratories for integration,

tests and simulations and testing tables for satellite or spacecraft subsystems.

On an immediate basis, this chapter includes the laboratories to be installed in the "Teófilo M. Tabanera" Space Center at Falda del Carmen, Province of Córdoba, and the telemetry and control systems for the follow-up of the satellites to be launched. It also comprises the performance of a feasibility study and the startup of the facilities recommended for obtaining CONAE's own data or that offered internationally (LANDSAT, SPOT, etc.), as well as for radioastronomical observations.

B - Satellite systems

This course of action includes all satellite missions, including the construction of satellites and platforms or space stations, as well as their subsystems for control, power generation, sensoring, communications, etc.

Considering the experience gained in projecting and building satellites, Argentina may face a successful program of light satellites, of up to a half ton, for scientific, teledetection, communication and other purposes. In our country, there are presently specific requirements in the areas of remote sensing and telecommunications that will not be satisfied by the systems offered internationally and that may be conveniently covered by our own light satellites.

On an immediate basis, missions will be performed with mixed-purpose satellites: for remote sensing and scientific research. Further on, this framework will be expanded to include satellites for microwave observation and communications (SAOCOM).

C - Data systems

This item comprises all the actions aimed at collecting, receiving, transmitting and storing data originated by space systems, including the development and operation of hardware and software systems, of computer networks and of data centers.

Both public agencies and private enterprises in our country have gained considerable experience in communication and computer network technology, as well as in the best use of images and of satellite data. Consequently, our country may well face development work concerning communications software and hardware, systems for data base management, systems on geographically-referenced applied data, systems for computer-aided design and manufacturing and event software for highly diverse types of engineering calculations. These are elements by which space activities may transfer its benefits to society, since they contain a great multiplying effect, allow for an easy capitalization of efforts and imply moderate investment costs.

On an immediate basis, this course of action shall emphasize the expansion of the service rendered by the Regional Center of Satellite Data (CREDAS) and the development of software concerning geographical data and image processing and simulation.

D - Access to space

Any actions performed towards allowing access to space by the various satellites included in the Space Program are included herewith. Stages such as feasibility studies, development, use and exploitation of spacecraft are contemplated, which allow for the exploration and best use of ultraterrestrial space.

This development work shall be carried out within the framework of full transparency and contemplating the possibilities offered by international cooperation programs, in accordance with Argentine policies on non-proliferation and with the international commitments assumed by our country in this matter.

On an immediate basis, the possibility of using the local experience in conceptual engineering for the development of a new generation spacecraft shall be evaluated. Such spacecraft should be useful for supplementing previous undertakings concerning light satellites and should demonstrate to be economically feasible, so as to progress towards a prototype within the first decade in the next century. A constant follow-up of the international market in this sector shall allow to assess the best opportunities for the concentration of material and human resources in these matters of the Space Program.

Any future undertakings regarding access to space shall be in agreement with the guidelines under which CONAE was created; that is, rejecting any military offensive use of space activities.

E - Institutional development and basic tasks

This course of action involves all the actions faced with regard to relations with other national and foreign institutions for the promotion, diffusion and utilization of space techniques and means or for project development in collaboration or with international cooperation. CONAE's tasks related to the training of human resources, through its Institute for Advanced Space Studies "Mario Gulich" and other educational activities are also included under this item and, especially, its contributions to distant education programs.

Also comprised in this course of action are the research and development activities to be performed with teams and laboratories of the Science and Technology System.

Development of human resources

The performance of training activities for human resources, aiming at satisfying the demand emerging from the actions scheduled in the Space Program, is considered as essential. In order to undertake these tasks, CONAE shall promote the development of its Institute for Advanced Space Studies "Mario Gulich", so as to transform it into an interdisciplinary center for the teaching of space sciences and of other related areas of knowledge.

The Institute will operate within the "Teófilo M. Tabanera" Space Center, at Falda del Carmen, Province of Córdoba, providing courses specially tailored for satisfying CONAE's needs, as well as those of companies involved in space activities. These courses will also be made available to students who are not directly associated with CONAE or with enterprises in this field. The Institute shall be given the juridical form considered as most appropriate in order to attain maximum self-financing.

CONAE's modi operandi

CONAE will approach its tasks through active links with entrepreneurial, public and private sectors and with research, technological development and teaching organizations. By means of these relations, it will use its best means for procuring the necessary complementation without increasing its permanent staff and its fixed expenditures. CONAE's role will be that of an agency taking care of planning, qualification, technical referencing, contracting, promoting and controlling.

Although maintaining certain features as an executor, CONAE will encourage performance by third

parties and will give preference to its role as a promoter of technological development, instead of participating in the granting of services or in everyday management or regular operation of facilities and equipment. Also, particular emphasis will be placed on the promotion of activities resulting in the technical qualification of human resources, suppliers and enterprises.

During all the time, CONAE shall preserve the necessary technical capacity required for establishing the basic definitions and the conceptual engineering of its programs underway. Basic and detailed engineering may be performed jointly by its personnel and ad hoc contractors. CONAE shall not develop any fabrication structure but, contrarily, it will retain a capacity for contract supervision and follow-up, as well as for controlling the acceptation and verification of quality and fabrication standards. Except for those cases in which particular standards are established, it will promote the creation of consortiums among users and operators, whose commitment shall be the utilization and operation of the space systems developed.

The above statements apply particularly to the field of telecommunications, which is nowadays the most significant segment among space activities. Within this field, CONAE shall try to offer its services as a "space architect", cooperating in the formulation of conceptual definitions and providing assistance in the selection of technological options, in the qualification and selection of suppliers and in contracting the space segments of the various projects. The role as a space architect excludes the further operation of the systems or the rendering of any regular services.

CONAE's projects and activities are aimed at realizing the successive missions of the Space Program, each one of them in connection with the satellites planned for the SAC and SAOCOM series. Each one of the missions shall coincide with the achievement of successive landmarks of the Space Program and shall have its own strict timetable of tasks and research and development work. Besides, they shall not only be connected to a definite goal that will be useful for national development, but mean a growing command of certain technological elements considered as particularly significant.

CONAE shall promote research and technological development programs, as far as they:

- Contribute to the creation or consolidation of an infrastructure of data and services by which space activities result to be profitable because of their social or economic impact.

- Are direct contributors to the technological development involved in the Space Program; and,

- Contribute to the enhancement of the advanced teaching staff dedicated to the generation of human resources for space activities.

Depending on the circumstances, CONAE shall promote research and development projects and activities by establishing a system for announcing opportunities for the performance of research and development contracts with institutions, researchers and technologists of the national scientific system, with tentative participation of companies from the production sector.

CONAE shall plan these research and development activities by framing them under the following **subjects**, which will be conveniently segregated as programs and subprograms:

- Subject # 1: Propagation and interactions of electromagnetic radiation.

- Subject # 2: Physics and chemistry of the atmosphere and the oceans.

- Subject # 3: Materials science and solid-state physics.
- Subject # 4: Applied mathematics and computation.
- Subject # 5: Solar-terrestrial physics and astrophysics.
- Subject # 6: Solid ground geophysics.
- Subject # 7: Space and microelectronics engineering and instrumentation.
- Subject # 8: Juridical, social, ecological and environmental studies.
- Subject # 9: The economics of space technology and business development.

6. MAIN OBJECTIVES

This section includes a listing of the general objectives for the tasks underway and for those to be performed in the short, medium and long term. Each one of the objectives is segregated into the main tasks, for which the most important and concurrent missions and actions are listed. They have been classified under the five courses of action defined above, while no mention is made of intermediate stages that will have to be fulfilled in every case.

The goals and tasks mentioned in the following sections must be considered as a basic sequence of actions aimed at complying with the main objectives of the Space Program. Should the conditions make it advisable, such goals and tasks may also be considered as the basis on which the objectives of the Space Program could be expanded to include other collateral undertakings that may both respect and supplement the achievements implicit therein.

Tasks underway (1995-1996)

General objective of the tasks underway (period 1995-1996):

Development and procurement of the means for the collection of space information

A) Land infrastructure:

1) Multipurpose ground station for the collection of satellite data and radioastronomical information.

2) Ground stations for satellite follow-up, telemetry and control and for signal reception.

3) Installation of a laboratory for integration and tests at the "Teófilo M. Tabanera" Space Center.

4) Restoration of facilities at Falda del Carmen (Prov. of Córdoba).

5) Development of compact ground stations.

B) Satellite systems:

1) Performance of the SAC-B Mission.

2) Preparation of the SAC-C Mission.

3) Conceptual development of a low-power radar satellite (SAOCOM 1).

4) Conceptual development of a satellite communications system (SAOCOM 2).

5) Conceptual feasibility of systems for modular satellite engineering (SAOCOM 1).

6) Development of orbit control systems (all missions).

C) Data systems and usage:

1) Development for the definition and usage of geographically referenced data bases (AIS).

2) Development of software for the simulation, capturing and processing of the available satellite data with SAC-B and SAC-C at the Regional Center of Satellite Data (CREDAS).

3) Expansion of the services rendered by CREDAS .

D) Access to space:

1) Analysis of conceptual alternatives on new generation spacecraft.

E) Institutional development and basic tasks:

1) Organization of the Institute for Advanced Space Studies "Mario Gulich".

2) Organization of a system for announcing opportunities, research contracting and performance control.

3) Research and development programs on:

- Earth validation of satellite sensors (Subjects 5 and 7).
- Valuation of the available data (Subject 4).
- Topics on materials science (Subject 3).
- Computation, systems and applied mathematics (Subject 4).
- Economics in space technology (Subject 9).
- New uses of space. Regulations in force, risks and consequences (Subject 8).

4) Coordination of actions and promotion of satellite data user groups.

5) Priority activities related to regional and international cooperation.

6) Library and documentation.

Short term (1997-2000)

Objectives in the short term (period 1997-2000):

Improvement of quality in available space data

A) Land infrastructure:

1) Building of compact ground stations.

2) Expansion of ground stations for follow-up, telemetry and control to assist in new space missions.

3) Operation of multipurpose ground station.

B) Satellite systems:

1) Operation of the SAC-B Mission.

2) Performance and operation of the SAC-C Mission.

3) Preparation and performance of the SAOCOM A/B-1 Mission (low-consumption radar and communications).

4) Preparation of the SAC-D Mission (spectrometry).

5) Design systems on the concept of modular satellite engineering (Subject 7).

C) Data systems and usage:

1) Image processing: subpixel modeling, microwave images, expert systems, high-speed processing systems, etc. (Subject 4) (CREDAS).

2) Geographical data systems interface with extensive data bases and geofluid numeric modeling (Subjects 2 and 4).

3) Extension of high-capacity computer networks (Subject 4) (CREDAS).

D) Access to space:

1) Conceptual engineering on new generation spacecraft (Subjects 3 and 7).

E) Institutional development and basic tasks:

1) Research and development support programs:

l Development of remote sensoring in the range of microwaves and ground validation. (Subjects 7 and 4).

l Development of multiple-band and multiple-frequency remote sensing and ground validation (Subjects 3, 7 and 4).

l Data administration in communications among satellites. Protocols for data transmission, understanding and storage (Subjects 1 and 7).

l Satellite on-board intelligence. Development of active antenna systems (Subjects 1 and 7).

l Feasibility of laser applications in space.

2) Cooperative programs within Mercosur.

3) Commercial viability of SAOCOM Missions (Subject 9).

Medium term (2001-2006)

Objectives in the medium term (period 2001-2006):

Improvement and expansion of space means for data collection.

A) Land infrastructure:

1) Expansion of infrastructure for follow-up, telemetry and control ground stations.

2) Expansion of infrastructure of integration and test laboratory.

3) Testing of spacecraft subsystems.

4) Ground infrastructure for use by the SAOCOM1-2 (operation of compact receivers).

5) Operation of multipurpose ground station.

B) Satellite systems:

1) SAOCOM1 A/B-1 Mission.

2) Replacement of the SAC line satellites. SAC-E Mission (Laser systems).

3) SAOCOM2 A/B-2 Missions.

4) Replacement/expansion of SAOCOM series.

C) Data systems:

1) Advanced geographical data systems with detailed positioning. Interface with on- ground mobile receivers (Subject 4) (CREDAS).

D) Access to space:

1) Operation and testing of subsystems for light spacecraft.

E) Institutional development and basic tasks:

1) Promotion of space exports.

2) Commercial viability of teledetection systems (Subject 9).

Long term (beyond year 2006)

Objectives in the long term (beyond year 2006):

Improvement and expansion of means in orbit. Use of space as a working environment: access to space and development of recoverable light satellites.

7. METHODOLOGY FOR PERIODICAL REVIEWS OF THE SPACE PROGRAM

The Argentine Space Program shall be reviewed every two years and its scope shall be extended for two additional years, so that a horizon of at least one decade shall always be available. In every occasion, it shall be tailored to the actual economic possibilities in the country and to the progress made during the last two years. For such updating, future missions shall be evaluated and defined, while adding or removing appropriate missions. Especially, worldwide advancement in space technology shall be taken into account, as well as the state of the art and the progress attained in the cooperative programs performed.

CONAE shall also apply an auditing system for its technical activities. For such purpose, a technical committee shall be appointed in every case, including at least three extensively well-known external specialists in the field of space activities, either from Argentina or from abroad.

Although, periodically, a detailed managerial control must be made of the Program, overall evaluations shall be performed all the time through the level of progress attained in the performance of the missions scheduled in the same. This is so, because each one of them corresponds with a major landmark in the progressive acquisition of the *SIC* technologies and they must be scheduled throughout time, so that the efforts performed in previous missions can be capitalized.

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